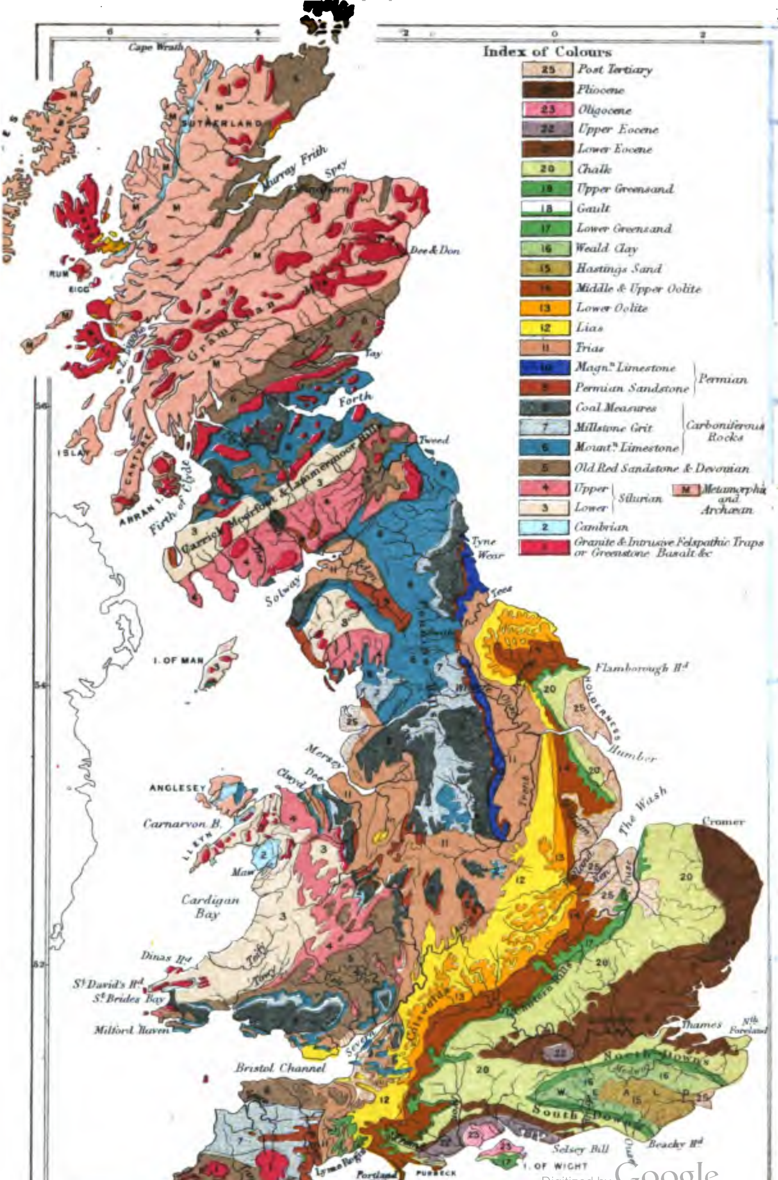
SOILS AND THEIR PROPERTIES.

DR. W. FREAM.



GEOLOGICAL MAP OF GREAT BRITAIN

SOILS

AND THEIR PROPERTIES.

BY

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INTRODUCTION.

THE soil, the plant, and the animal alike claim the attention of the agriculturist. It is, however, hardly an exaggeration to say that, in many respects, our knowledge of the soil is least. What is the soil? What is the true nature of the mysterious changes that take place in its dark recesses? The view that the soil was merely a mass of mineral matter, of lifeless material, from which plants could select what was suitable to their growth and development, is, according to modern notions, no longer tenable. Recent research has demonstrated the existence in the soil of minute living organisms, the exercise of the functions of which is intimately associated with the preparation and presentation of plant-food. By the activity of these organisms the humus and ammonia existing in the organic matter of the soil are oxidised, and their nitrogen is converted into nitric acid. As the result of this process of nitrification the nitrates which are produced present their nitrogen in a form in which it can enter the plant in solution. Not less significant are the functions, still under investigation, of those micro-organisms which appear to act as carriers of nitrogen between the enormous reservoir of this element contained in the atmosphere and the roots of leguminous plants. Hence, besides the geology of the soil, the chemistry of the soil, and the physics of the soil, modern science must equally find a place for the biology of the soil.

The recognition of the work done by micro-organisms marks a most important advance in our knowledge of the phenomena involved in the metabolism (Gr. *metabole*, change) of the soil. Hitherto, investigation has been directed rather to the determination of the immediate effects of soil metabolism in promoting the nutrition of plants. But it is at least possible that the biological factors in metabolic activity may eventually be proved to be not less potent than the physical and chemical agents in effecting the disintegration of rocks, and thus in restoring to the soil those mineral ingredients which are undergoing incessant loss.

Our knowledge of the biology of the soil is hardly yet in a sufficiently settled condition to be made the subject of an elementary manual. All that is attempted, therefore, in the following pages is to trace soils back to their parent rocks, to indicate some of their more important physical and chemical properties, and to give a brief account of the distribution of soils within the British Isles. It is proposed to follow this volume with another, in the same series, upon the practical management of the soil.

In the section dealing with igneous rocks and their derivatives I have followed very closely the lines laid down by Professor Prestwich in his admirable work, "Geology: Chemical, Physical, and Stratigraphical." To the veteran geologist I am further indebted for most of the analyses of rocks; though in an elementary book it did not seem necessary to give the author of each analysis. I have also had recourse to the well-known manuals of Professor A. H. Green and Sir A. Geikie, whilst Mr. H. B. Woodward's "Geology of England and Wales" has afforded me many useful hints for the section treating of

the distribution of soils. No student of the subject of soils can venture to ignore the precise and elaborate investigations which, for more than half a century, Sir John Lawes and Sir Henry Gilbert have prosecuted at Rothamsted, Hertfordshire. I have, therefore, particularly in the section concerned with the relations of water to the soil, not hesitated to avail myself of the opportunity thus afforded to attempt to popularize a series of valuable and significant facts, other details relating to which may be found in my book on "The Rothamsted Experiments." Several sections I have revised from my former contributions to the *Journal of the Royal Agricultural Society of England*, to the *Transactions of the Surveyors' Institution*, and to other publications. Most of the woodcuts are taken from the geological works of Mr. A. J. Jukes-Browne, F.G.S., published by Messrs. George Bell & Sons. Further obligations are acknowledged in the text.

We have in our own language nothing comparable with M. Risler's exhaustive treatise, "Géologie Agricole." The wealth of reference in that comprehensive work renders it, however, specially valuable to the French rather than to the English student. Nevertheless, this little volume will hardly fail in its purpose should it be found competent to indicate in a small way those facts and principles which M. Risler has so successfully demonstrated on a much larger scale.

A SECOND edition having been called for, the text has been revised throughout, and, at the same time, an effort has been made to introduce such additions as the results of investigation during the last few years have rendered possible.

W. F.

March, 1895.

SOILS AND THEIR PROPERTIES.

THE ORIGIN OF ROCKS.

Soils form a merely superficial covering of certain parts of the dry land which occupies a portion, though not the greater portion, of the surface of the globe. By digging down to a certain depth, usually a moderate depth, it is always possible to expose rocky material — limestone, sandstone, clay, gravel, granite, or some other kind of rock [1]—differing from the more or less thin layer of soil which hides it. Any question as to the origin of soils must obviously lead back to an inquiry into the origin of the rocks which underlie the soils. To this inquiry geologists have furnished an answer that is at once intelligible and natural.

The globe on which we live, and which we call the Earth, was once in a highly heated condition, the intensity of the heat being so great that the materials composing the rocks which we now see around us were as fluid as molten metal. In the course of ages, much of the earth's heat was radiated into space; and this went on till at length the earth became sufficiently cooled for some portion of it to assume the solid state. It was probably in this manner that the first hard rock-masses made their appearance on the earth's surface. As the cooling continued, the water-vapour, or steam, which

[1] The geologist uses the word *rock* to denote any large mass of earthy matter, whether *hard* or *soft*.

must have been present in the hot atmosphere, became condensed into the liquid state; the water itself was then subjected to the cooling influence of radiation; and in course of time the earth's surface became inhabited by low forms of life. The effect of the sun's heat in those far-distant ages would be then, as now, to cause the water on the earth's surface to rise up in the form of vapour, and so to form clouds. These clouds, floating about in the higher regions of the atmosphere, would become sufficiently cooled for their water-vapour to be condensed and fall in the form of drops—rain-drops—on the earth. The rain-water would flow over the surface, or percolate through the rock-masses, and some of it would at length find its way into little channels, whence the water would emerge in rills; and by the confluence of a number of rills a larger stream would be formed, the waters of which would in the end empty themselves into some large reservoir, as a lake or the sea.

But what is the effect of falling rain and running water on the land surface of the globe? To answer this question, it is only necessary to observe the results produced by a shower of rain. Every one has noticed that the rain, as it drains off the land, is by no means clear water, but that it is turbid or muddy, owing to the fact that the running water takes up in its course and carries along with it small particles of earth. Water may either flow off the surface of the land into some small stream, and thence to a river, or it may first trickle through the earth's "crust," and so find its way by a different course into a large stream. All rivers contain fine mud or sediment in their water, some, indeed, being always obviously muddy; and even those whose waters appear to be bright, clear, and sparkling, are only apparently clear,

for if a glass of the clearest river water be set aside for an hour, a fine layer of sandy particles will be seen to have settled down on the bottom of the vessel. It is evident, then, that the effect of running water is *to wear away the surface of the land;* hence water is called a *denuding* agent, because, when in motion, it *lays bare* the rock-masses on the face of the earth. And this denuding action of water, be it remembered, has been in progress in various parts of the earth ever since the time when water first appeared, as such, on the globe, though the intensity of the action may have been, and probably was, greater in former times than it is now.

The work of *denudation* implies also that of *disintegration*, by which is meant the breaking up of the rock-masses into small particles, capable of being easily transported from place to place. This process of disintegration having happened, the denuding action of running water easily follows. A moment's consideration will show that, besides running water, there are several other important agents of disintegration. Thus, the great reservoir of water, the ocean, is incessantly beating with its restless waves upon the rock-bound shore, angular fragments of rock being thereby broken off the parent mass. These, by being continually rolled about, become rounded into pebbles; and the smaller fragments at length form those very small pebbles called sand. And this *marine denudation*, as it is called, is always going on to a greater or less degree—the huge, angry breakers, urged on in their resistless course by the fiercest hurricane, and the gentlest ripple of the ocean wave on a calm summer day, alike perform slowly but surely their work of destruction. Other causes are not less potent: frozen water, in the form of snow and ice, for example, exerts a destructive effect

on the land; glaciers grind away the rock surface over which they flow, scratching and polishing the rock itself, and bearing away to the place where the glacier melts the disintegrated particles, which are then further transported by the streams that flow from the melting glacier. The river Rhone is fed in this way by the streams from the Alpine glaciers, and before entering the Lake of Geneva is a very muddy river. The Rhine is another river whose source is to be sought in the glaciers of the Alps; whilst the upper tributaries of the Mississippi are fed by the glaciers of the Rocky Mountains, and many of the great rivers of Northern India can be traced back to the glaciers of the Himalayas.

The destructive effects of water, then, are produced by both its liquid and its solid forms; and not only is this so, but in the very act of passing from the liquid to the solid state—that is, in freezing—this agent exerts an influence which is not less effective. For water, unlike most other substances in nature, instead of contracting, expands when it is in the act of freezing, and the power of this expansion is well-nigh irresistible; consequently, if a rock soaked with water becomes frozen, the water between the particles of rock will, in expanding into ice, force these particles farther apart. As long as the ice remains solid, it will act as a cement between the disrupted particles; but as soon as a thaw sets in, the crumbling effect will at once make itself apparent, and the particles will be easily carried away in the water that trickles out of the rock. It is in the same way that the bursting of a water-pipe by frost, though it occurs at the time of freezing, yet is found out only when the thaw sets in. The effect of a frost on a soil is to make it lighter, for the freezing water pushes apart the constituent parti-

cles. Lastly, the moving currents of air, which produce wind, may be referred to, as transporting agents which carry clouds of fine sand and dust, resulting in marked effects on sandy beaches and loose soils.

An important pre-disposing cause to disintegration is the solvent effect which water exerts upon many of the substances which help to form rocks. By the removal of these substances in solution, the fabric of the rock is weakened, so that it more easily succumbs to the ordinary physical agencies. All natural waters contain such dissolved material, as is shown by their leaving a deposit when they are boiled away.

It should now be evident that, by means of the various agents indicated, the earth's surface is undergoing continuous waste; and the question naturally arises, How is it that, notwithstanding the waste and denudation which have for so long been going on, the whole of the land has not been reduced to one dead level beneath the sea? Clearly there must be some opposing force, some counteracting influence, at work; and, as a matter of fact, this opposing force has its origin in that residuum of the earth's primeval heat which is still stored up in its interior. Geologists have shown that the effect of this internal heat is to cause oscillations in the earth's surface, so that while it is slowly rising in one place it is slowly sinking in another. Thus, the north of Scandinavia is at present being upheaved, while the south of Scandinavia and the west ot Greenland are as certainly undergoing depression. Labrador, Newfoundland, and Hudson's Bay afford evidence of elevation. These processes are of extreme slowness; but occasionally the earth's internal heat manifests its existence in a very violent and decisive manner, as in a volcanic eruption,

when vast quantities of molten matter, ashes, and gases are ejected from the earth's interior; or in an earthquake, when the very "foundations of the earth" appear to be shaken, and the surface becomes as unstable as that of the ocean.

Though the process of disintegration may appear at first to be solely destructive, it is not really so, for it must be borne in mind that the mud-laden waters of rivers and other streams are, in the end, poured into lakes or seas, and there the same thing occurs as happens when a glass of water is taken from a river—the sediment becomes in time deposited, on account of the velocity of the water being checked. The coarsest, and therefore the heaviest, materials, such as the larger pieces of gravel and the stones rolled along the bottom of the river, are deposited nearest the mouth, while the lighter particles are carried farther out, and the finest sediment farthest of all. It is because of this deposition of sediment that the Rhone, which, as has already been stated, enters the Lake of Geneva as a muddy stream fed by glaciers, emerges therefrom as a river of clear, pellucid water. Deltas, such as those of the Nile and the Ganges and Brahmaputra, and the delta of the Rhine, which forms most of the flat Dutch country, have originated in this way. The Mississippi, the Tiber, and the Po are other examples of rivers which are now forming deltas. If, however, the river-current be very swift, as is the case with the Amazon, for example, a delta is not formed, nor again where the scouring action of oceanic currents disturbs the water at a river's mouth.

The sediment, as it is deposited on the ocean-floor, is at first loose and incoherent—shifting sand or mud—but gradually, owing to the pressure of other sediment de-

posited on it, and to the percolation through the mass of certain cementing materials (carbonate of lime, soluble silica, oxides of iron, etc.), it will in time become a firm coherent rock-substance, as sandstone or clay. Rocks formed thus by the agency of water are called *aqueous* rocks, while those produced by the action of the earth's heat are termed *igneous*. There is an intermediate class, in which are placed rocks which were formed as aqueous rocks, but which by the deposition of other rocks upon them, accompanied by the slow sinking of the ocean-floor, have gradually come to occupy deep positions in the earth's crust, and there, under the influence of great pressure, heat, and perhaps steam, have assumed more or less the character of true igneous rocks without really being so; such rocks are said to be metamorphosed or altered, and they are called *metamorphic* rocks. Gneiss, serpentine, marble, and schists may be mentioned as examples. By subsequent upheaval, and denudation of the overlying strata, these metamorphic rocks may again be exposed at the surface.

Usually, it is not difficult to determine whether a rock is of aqueous or of igneous origin. Aqueous rocks are (1) granular in texture, (2) exhibit planes of bedding—lamination or stratification—due to deposition in layers, and (3) frequently enclose mineralized remains of animals and plants (fossils). Igneous rocks, on the other hand, are (1) crystalline in texture, (2) do not show lamination, and (3) never enclose fossils. Familiar examples of aqueous rocks are sand, sandstone, clay, marl, limestone, coal, rock-salt; common igneous rocks are granite, basalt, and pumice. Aqueous rocks, as they occur in the earth's crust, are usually *stratified*—that is, arranged in layers; igneous rocks are *unstratified*.

All the rocks which at any one period appear as dry land are alike subject to the influence of disintegrating agents. Hence, by the continued denudation of the land accompanied by slow upheaval, it would be possible for igneous rocks, which had originally solidified deep down in the earth's crust, to appear at the surface. Further, although aqueous rocks may, at first, have been deposited horizontally, yet, owing to movements of the earth's crust, caused by its endeavour to accommodate itself to the contracted interior resulting from the radiation of the earth's heat into space (a process which is still going on), the horizontal layers become first tilted, and then thrown

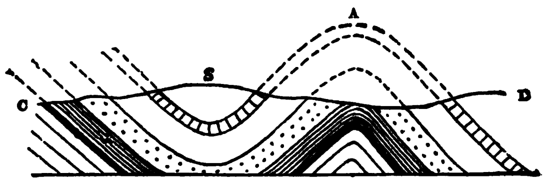

Fig. 1. Strata thrown into Curves.

into curves, these movements being necessarily accompanied by great straining, tearing, crushing, and contortion of the rocks. The tops of the curves then get planed off by denudation, and so the surface of the land may really consist of the *upturned edges* or *outcrops* of the beds. This is to a great extent the case in England, where a rapid succession of beds or *strata* is passed over in travelling from the west coast of the country to the east (see map); and these strata are known to *dip* down into the earth with a gentle inclination to the east, each stratum overlying the one on its west side.

The section, Fig. 1, represents a series of beds thrown into curves in this way, the upper parts, represented by

dotted lines, having been swept away by denudation, the present land surface being denoted by the letters C, S, D. The portion of the curve shown at S, where the strata appear to form a basin or hollow, is termed *synclinal*, while at A, where the strata rise up into a ridge, an *anticlinal* curve results. The other section, Fig. 2, shows how originally continuous beds may be thrown into curves, and separated by denudation into isolated regions.

As a result of their investigations, geologists have succeeded in constructing a list of strata in the order in which they were formed. Such a list, as it refers to the

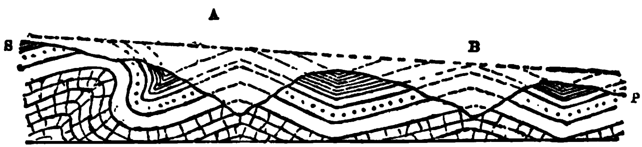

FIG. 2. EROSION OF CURVED STRATA.

S P—Surface of Planation. A B—Valleys coinciding with Anticlinals.

British Isles, is given on the next page, the youngest rocks being placed at the top, and the oldest at the bottom; beneath all these stratified formations, and often deep down in the earth's crust, there are, of course, igneous rocks (fig. 3). The approximate thicknesses are not given, as all strata vary considerably in this respect; and further, the thickness can afford no indication of the extent of rock exposed at the surface, as this will depend rather on the nature of the outcrop and the angle of dip. In the last column are mentioned some of the useful mineral products derived from the several formations. The names of the various groups are sometimes intended to be descriptive of the rocks themselves (as Cretaceous,

THE STRATIFIED ROCKS OF THE BRITISH ISLES.

Period.	*Epoch.*	*Series.*	*Formation.*	*Economic Products, etc.*
QUATERNARY.	PLEISTOCENE	POST-GLACIAL	Loess; Raised Beaches	Peat, lignite.
			Valley-Gravels; Bone Caves	River mud at mouth of Thames for Portland cement.
		GLACIAL	Boulder-Clays, Gravels, and Sands	
			Clyde Shell-beds	Loam.
		PRE-GLACIAL	Westleton Sands and Shingle, and Bure Valley Crag	Flint-gravel.
			Forest and Elephant-beds	
CAINOZOIC, OR TERTIARY.	PLIOCENE		Chillesford and Cromer Beds	
			Norwich and Red or Upper Crags	Phosphatic nodules, used as mineral fertilizers.
			Lower or White (Coralline) Crag	Building stones.
	MIOCENE		Lenham Sands (?)	
	OLIGOCENE	UPPER	Lignites of Bovey Tracey (?)	Pottery clay and lignite.
			Hempstead Beds	Clay for brick-making.
		MIDDLE	Bembridge and Osborne Beds	Sand for glass-making.
		LOWER	Headon Hill and Brockenhurst Beds	Ironstone.
	EOCENE	UPPER	Barton Clay and Sands (Upper Bagshots (?))	Septaria for making hydraulic cement.
			Bracklesham Sands (Middle Bagshots)	Sand for glass-making.
		LOWER	Lower Bagshot Sands	
			London Clay and Basement Bed	London clay for making bricks and tiles.
			Woolwich and Reading Series	Septaria dredged up off coasts of the London clay.
			Thanet Sands	
OR SECONDARY.	CRETACEOUS	UPPER	Upper Chalk with flints	Chalk, whiting, lime, building-stones; flint for road-metal and glass-making.
			Lower Chalk without flints	
			Chalk Marl	Chalk and marl for dressing land.
			Chloritic Chalk	
			Upper Greensand	Phosphatic nodules.
			Gault and Folkestone Beds	Gault clay for bricks and tiles.
		LOWER, OR NEOCOMIAN	Lower Greensand	Kentish Rag building-stone; clay; fuller's earth.
			Atherfield and Punfield Beds	
			Weald Clay	Speeton clay of Yorkshire yields septaria for Roman cement, and fine, light-coloured clay for Portland cement.
			Hastings Sands	
	JURASSIC	UPPER OOLITES	Purbeck Beds	Purbeck "marble."
			Portland Stone and Sands	Building-stone.
			Kimmeridge Clay	Clay.
		MIDDLE OOLITES	Coral Rag } Coralline Oolite	Building-stone.
			Calcareous Grit } Coralline Oolite	Road-stone.
			Oxford Clay	Freestone.
			Kelloway Rock	
			Cornbrash	
			Forest Marble	Roofing-tiles.

MESOZOIC,		Lower Oolites	Bradford Clay	Clay.
			Great (or Bath) Oolite and Stonesfield Beds	Bath freestone.
			Fuller's Earth	Fuller's earth.
			Inferior Oolite	Coarse building-stone.
			Sands of Inferior Oolite	Iron ore from Northampton sands.
		Liassic	Upper Lias	Coal in Sutherlandshire.
			Middle Lias, or Marlstone	Alum, Whitby jet, clay for bricks, tiles, and drain-pipes.
			Lower Lias	Cleveland (Yorkshire) iron ore.
			White Lias	Clay for bricks and tiles, nodules for cement.
	TRIASSIC	Upper	Rhætic or Penarth Beds	Landscape "marble" of Cotham.
			Upper New Red Sandstone (Keuper)	Gypsum (sulphate of lime); common sorts burnt for plaster of Paris, very coarse kinds used as top-dressing for soils. Rock-salt.
		Middle	(*Wanting.*)	
		Lower	Lower New Red Sandstone (Bunter)	Bunter yields good supply of water.
PALÆOZOIC, or PRIMARY.	PERMIAN, or DYAS	Upper	Upper Red Sandstone and Marls	Building, paving, and road-stones.
		Lower	Magnesian Limestone and Marl-slates	
			Lower Red Sandstone and Breccias	
	CARBONIFEROUS	Upper	Coal Measures	Coal, iron ore, clay for bricks, tiles, and pottery. Stourbridge clay for fire-bricks. Grindstones.
			Millstone Grit	Iron pyrites; lead ore.
			Yoredale Rocks	Barytes; fluorspar; ores of zinc and lead.
		Lower	Carboniferous or Mountain Limestone	Good road-metal, coal and blackband ironstone in Scotland.
			Lower Carboniferous Shales, etc.	
	DEVONIAN (OLD RED SANDSTONE)	Upper	Upper, or Pilton group	Flagstones, paving and building-stones.
		Middle	Middle, or Ilfracombe group	Clay-slate in Devon and Cornwall, containing ores of tin, copper, lead, iron, and silver.
		Lower	Lower, or Lynton group	Madrepore marble.
	SILURIAN	Upper	Tile-stones and Bone-bed	Building-stones.
			Ludlow Beds	Lime and flux for iron-smelting.
			Wenlock Limestones and Shales	Green slates.
			Mayhill Sandstones	
		Lower	Llandovery Beds	
			Bala and Caradoc Beds	Limestone burnt for manure; phosphate of lime; jasper.
			Llandeilo Flags	
			Arenig Schists	
	CAMBRIAN	Upper	Tremadoc Slates	Slates, paving-stones, flag-stones.
			Lingula Flags	Roofing-slates, slabs for cisterns, and hones for cutlery.
		Lower	Menevian beds	
			Longmynd beds	Largest slate quarries in the world at Penrhyn, N. Wales.
	ARCHÆAN		Pre-Cambrian and Laurentian	Plumbago, or graphite. Building materials.

Oolite), or they may be of geographical origin (as Wealden, Jurassic, Permian, Devonian), or they may refer to the nature of the enclosed organic remains (as Pliocene, Eocene); the first-named are objectionable, because the same formation may vary considerably in the nature of its rocks in different localities. Moreover, it should be distinctly understood that the names are primarily intended to indicate periods of time, so that it is quite proper to speak of the Cretaceous period, the Permian period, and so on; and likewise to infer that the Miocene period, for example, was more recent than the Eocene,

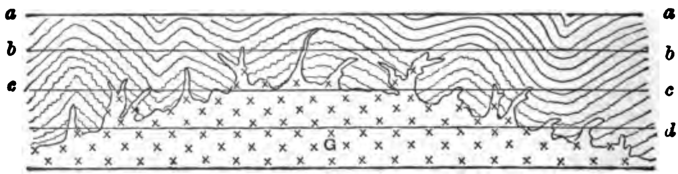

FIG. 5.

DIAGRAM ILLUSTRATING THE INTRUSION OF GRANITE, THE OVERLYING ROCK BEING SLATE.

The lines *a a*, *b b*, etc., indicate successive surfaces of denudation, more and more of the granite becoming gradually exposed.

and the Carboniferous period than the Devonian or the Silurian. It is, however, by no means implied that these periods were ot equal duration; as a matter of fact they were far from being so. Nor must it be assumed that the rocks of the Cretaceous period are necessarily of a cretaceous character, for though this is true of the Chalk it is manifestly untrue of the Gault Clay and the Greensand. Again, in the Carboniferous period, although the Coal Measures may properly be described as carboniferous or carbonaceous in character, this term would be quite inappropriate if applied to the Millstone Grit or the Car-

boniferous Limestone rock. Nor should it be inferred that the strata of a certain geological age in one district are lithologically similar to strata of the same age in another locality or country—they may or may not be similar, according to circumstances.

The earth's surface is mostly occupied by aqueous rocks, those of igneous origin being more or less covered by these. So long as the aqueous rocks rested beneath the protecting covering of the ocean they were preserved from denudation, but directly they emerged above the sea their destruction was commenced, and is still going on, the result being apparent to every one who is willing to look for it. All the diversified forms that delight the eye of the traveller or the tourist,—crags, peaks, and fells; scarps, cliffs, and precipices; gorges and ravines; glens, dells, straths, and valleys; hills and dales; plains and table-lands,—in a word, all the varied forms of scenery which, associated with a mantle of verdure, make the face of the earth lovely and beautiful,—have been produced by the unceasing action of rain and frost, of rivers and the sea, by nature's two great sculptors, water and ice.

CLASSIFICATION OF ROCKS.

A CONVENIENT classification of rocks may be founded upon their different modes of origin; and such a classification is presented in Table I. on the opposite page.

Igneous rocks may be of any age, and though many areas of such rocks are geologically very old, it is incorrect to suppose that all igneous rocks are necessarily of great age. Some, indeed, of the very youngest rocks are of igneous origin, as is exemplified in the additions to the rocks of the surface which are at the present time being made wherever volcanoes are pouring forth their molten flood. As a matter of fact, therefore, igneous rocks may be, and are, of any age from the oldest to the youngest; and in some cases their geological age can be fixed with tolerable accuracy from a full consideration of the circumstances under which they naturally occur. From an agricultural point of view it is immaterial whether such rocks "have been ejected or have welled out on the surface, and have therefore cooled and consolidated rapidly" (Volcanic rocks), or "have been formed under conditions of depth and pressure, and have cooled slowly" (Plutonic rocks); in each case they weather down into very much the same kind of soil.

Igneous rocks are, as the name implies, those which have been produced by the agency of fire, or of intense heat. The term is applied to all rocks which have cooled from a molten state. If they have at any time

during the earth's history been erupted through the overlying sedimentary strata (aqueous rocks), they are distinguished as volcanic rocks. If, on the other hand, they

TABLE I.—CLASSIFICATION OF ROCKS ACCORDING TO THEIR MODES OF ORIGIN.

IGNEOUS.

- VOLCANIC.
  - *Examples.*—Dolerite, Basalt, and all Lavas and Trap rocks.
  - Trachyte, Obsidian, Phonolite, Pumice, Volcanic Ash.
- PLUTONIC.
  - *Examples.*—Granite, Syenite, Pegmatite, Porphyry, Felsite, Pitchstone.
  - Diorite, Diabase, Gabbro.
  - Serpentine.

AQUEOUS.

- MECHANICALLY FORMED, OR SEDIMENTARY.
  - *a.* Argillaceous, or Clayey.
    - *Examples.*—Mud, Clay, Till, Boulder-clay, Fuller's Earth, Clunch, Loam, Shale, Marl.
  - *b.* Arenaceous, or Sandy.
    - *Examples.*—Sand, Silt, Sandstone, Flagstone, Grit-stone.
    - Gravel, Rubble, Shingle, Conglomerate, Breccia.
- CHEMICALLY FORMED.
  - *Examples.*—Rocksalt, Gypsum, Travertine (river limestone, or calcareous tufa).
- ORGANICALLY FORMED.
  - *a.* By Animals.
    - 1. Calcareous.
      - *Examples.*—Limestones (Shell-marl, Coral-rock, Chalk, Oolite, Magnesian Limestone, "Mountain Limestone," etc.).
    - 2. Siliceous.
      - *Examples.*—Diatom-earth, Flint, Chert.
    - 3. Phosphatic.
      - *Examples.*—Guano, Bone-breccia, Phosphatic nodules and beds (coprolites).
  - *b.* By Plants.
    - 4. Carbonaceous.
      - *Examples.*—Peat, Lignite, Coal, Oil-shale, Petroleum, Asphalt, Graphite.
    - 5. Ferruginous.
      - *Examples.*—Bog iron-ore, Clay ironstone.

METAMORPHIC.

- *Examples.*—Crystalline Limestone (Marble), Dolomite, Quartzite, Clay-slate.
- Schistose Rocks (Mica schist, Hornblende schist, Talc schist, Chlorite schist, Calc schist, Gneiss).
- Certain Serpentines, Granites, and Syenites.

have solidified at some depth beneath the surface, they are called plutonic rocks. Igneous rocks are usually crystalline in texture and unstratified. The general character of the chemical composition of igneous rocks will be understood by an examination of Tables II. and III.

Some of the older terms applied to igneous rocks are still usefully retained. Thus, Felstones are those felsitic and porphyritic rocks which are composed largely or chiefly of felspar. The Greenstones include diorite, gabbro, diabase, and some of the older and coarser dolerites, all having a greenish colour. Greystones are certain greyish compact felsites, trachytes, and lavas.

Aqueous rocks are those which have been deposited in water, and hence they usually exhibit stratification, and possess a granular texture. The mechanically formed, or sedimentary, rocks are built up of the mineral detritus which is carried by streams into lakes and seas. The

TABLE II.—CHEMICAL COMPOSITION OF CERTAIN IGNEOUS (PLUTONIC) ROCKS.

	Grey Granite. Cornwall.	Red Granite. Peterhead.	Felsite. Dopenheim.	Pitchstone. Arran.	Syenite. West Aston.	Melaphyre. Spiemont.	Diorite. Hartz.	Trap. Sweden.
Silica	69·64	73·70	77·42	73·00	52·08	51·62	51·07	50·22
Alumina	17·35	14·44	10·00	12·27	15·60	20·44	22·12	14·97
Lime	1·40	1·08	0·76	0·50	6·52	1·39	6·11	10·48
Magnesia	0·21	traces	0·36	—	8·40	4·38	2·09	5·76
Potash	4·08	4·43	5·20	4·32	3·80	4·22	3·25	1·62
Soda	3·51	4·21	1·13	3·64	2·92	5·81	4·11	2·20
Iron peroxide	1·97	1·49	—	1·50	2·57	5·15	9·28	15·76
Iron protoxide	1·04	0·43	2·69	—	5·75	—	—	—
Manganese protoxide	traces	traces	—	—	—	—	—	1·13
Water	1·09	0·61	1·15	5·12	2·24	3·91	1·21	0·70
	100·29	100·39	98·71	100·35	99·88	96·92	99·24	102·84

TABLE III.—CHEMICAL COMPOSITION OF CERTAIN IGNEOUS (VOLCANIC) ROCKS.

	Trachyte. Drachenfels.	Pumice. Santorin.	Phonolite. Mont Dore.	Basalt. Staffa.	Lava. Vesuvius. 1631.	Lava. Teneriffe.
Silica	65·07	69·79	59·84	44·50	48·12	48·64
Alumina . . .	16·13	12·31	23·07	16·75	17·16	22·92
Lime	2·74	1·68	1·48	9·50	9·84	9·02
Magnesia . . .	0·67	0·68	0·25	2·25	3·99	3·91
Potash. . . .	4·44	2·02	4·13	—	7·24	1·04
Soda	4·47	6·69	4·52	2·60	2·77	1·89
Iron protoxide .	—	—	traces	20·20	5·13	5·98
Iron peroxide .	5·17	4·66	3·35		5·69	5·07
Manganese protoxide	—	—	traces	0·12	1·20	0·14
Water and other substances. .	0·70	2·93	3·20	2·00	0·30	0·37
	99·39	100·76	99·84	97·92	101·44	98·98

chemically formed rocks arise from the precipitation, caused usually by supersaturation, of the saline matters which have been dissolved out of rocks by the water which percolates through them. Organically formed rocks are due to the gradual accumulation of the remains of animals or plants: the calcareous shells of molluscs falling to the bottom of the ocean will, in time, form a bed of limestone; and the continued growth and decay of vegetation, century after century in the same place, may give rise to peat or lignite.

Metamorphic rocks are those of which the original character has been altered, in which new chemical combinations have been formed, and of which the structure has become more or less crystalline. By metamorphism, limestone may be converted into marble, sandstone into quartzite, clay into slate, and slate into schist, or even into gneiss. The characters of metamorphic rocks thus ap-

proximate to those of true igneous rocks, sometimes to such an extent that it is difficult or impossible to distinguish between them. Some metamorphic rocks are distinctly foliated or laminated, owing to the crystallization of the minerals in parallel layers, often wavy. Such

TABLE IV.—CHEMICAL COMPOSITION OF CERTAIN METAMORPHIC ROCKS.

	Roofing-slate. Wales.	Roofing-slate. Camelford.	Mica-schist. Pyrenees.	Chlorite-schist. Hartz.	Killas-slate. Cornwall.	Gneiss. Hartz.
Silica . . .	60·50	58·35	71·26	3·72	50·80	65·22
Alumina . .	19·70	22·04	20·03	9·81	20·90	16·35
Lime . . .	1·12	0·39	0·28	0·60	1·56	3·27
Magnesia . .	2·20	1·10	traces	12·01	trace	2·06
Potash . .	3·18	2·45	2·48	} traces	0·91	2·74
Soda . . .	2·20	1·23	0·59		4·20	8·03
Iron protoxide	7·83	2·57	3·61	21·83	5·14	1·00
,, peroxide	—	6·96	1·10	—	13·39	—
Titanic acid .	—	0·23	—	—	trace	—
Water . . .	3·30	4·60	1·63	9·27	3·20	2·25
	100·03	99·92	100·98	10[illegible]·24	100·10	100·92

	Crystalline Limestone (Carrara marble).	Crystalline Limestone. Tiree.	Dolomite. Italian Alps.	Quartzite.
Silica	—	—	—	97·75
Carbonate of Lime	98·1	94·94	53·4	—
Do. Magnesia .	0·9	1·13	44·2	—
Do. Manganese .	1·0	3·19	2·4	—
Alumina and Iron.	—	0·54	—	0·50
Water	—	—	—	1·00
Loss	—	—	—	0·75
	100·0	99·80	100·0	100·00

rocks are described as schistose, because they can be split along the layers.

Though a classification of rocks based upon their mode of origin is extremely useful from a geological point of

view, it is not of primary importance to the agricultural student. For him the chief questions concerning any rock are not so much, "How did this rock originate?" as, "What is this rock composed of?" and, "What kind of soil will it weather, or break down, into if exposed to the atmosphere?" To illustrate this point, take the case of three such rocks as granite, gneiss, and slate. Ordinary specimens of these differ so much from each other in appearance that it would be almost impossible, after once having learnt to identify them, to mistake one for another. They differ, too, in their mode of origin. And yet they will, on an average, weather down into much the same kinds of soil, because they consist of approximately the same chemical components (as is seen in the Analyses which have been given). Flint and sandstone, again, are of widely different origin, yet they may be ground down into powders which are chemically identical. Rocks consist of minerals, and minerals are definite chemical compounds, such as Quartz (chalcedony, jasper, opal), Felspar (orthoclase, oligoclase, albite, labradorite, anorthite), Mica (muscovite, biotite, lepidolite), Hornblende (actinolite, tremolite, asbestos), Augite, Talc, Calcite, Gypsum, Apatite, Fluorspar, etc. To the geologist the mineral constitution of rocks is of great importance. The knowledge that some rocks—such as sandstone, limestone, and rock-salt—consist each of one mineral, whilst other rocks—such as basalt, gneiss, and granite—consist each of a mixture of minerals, is of great use to him. He learns further, that whilst granite and gneiss both have the same mineral composition, consisting as they do of quartz, felspar, and mica, they are, nevertheless, on account of their structure, usually readily distinguishable the one from the other. As rocks are broken down by natural

agencies into soils, and the constituent minerals are thereby destroyed, it is obvious that in the study of soils a knowledge of the ultimate chemical composition of rocks is of more immediate interest than an acquaintance with their mineral constitution. This latter point need not, therefore, be further touched upon.

The number of known minerals is about 600, of which not more than thirty enter as essential constituents into the structure of rocks; and even of these thirty only a third play an important part. In minerals, the proportions of the constituent elements are definite and fixed, whereas, in rocks the component parts are indefinite and mixed in variable proportions. Different granites, for example, contain variable percentages of quartz, of felspar, and of mica. Hence, whilst the number of species of rocks is variously estimated at from 200 to 300, the number of varieties is exceedingly great. On the assumption that the solid crust of the earth consists, on the average, of a thickness of three miles of sedimentary strata and fifty-seven miles of crystalline and igneous rocks, it has been estimated that, taken together, the relative proportion of the ten most abundant minerals is in this mass about as follows:—

TABLE V.—PERCENTAGE MINERAL COMPOSITION OF THE ROCKS OF THE EARTH'S CRUST.

1. Felspar	48
2. Quartz	35
3. Mica	8
4. Talc	5
5. Carbonates of Lime and Magnesia	1
6. Amphibole (Hornblende) 7. Pyroxene (Augite) 8. Diallage 9. Peridot (Olivine)	1
10. Clay (in all its forms)	1
11. Other substances	1
	100

This table indicates that more than four-fifths of

the rocky material which constitutes the crust of the earth consists, probably, of felspar and quartz. The felspars are double silicates of alumina and of potash, or soda, or lime. Quartz is silica, or oxide of silicon, which is seen in a fairly pure form in the fine sand of the seashore. The micas are silicates of alumina, and of potash or magnesia, usually with some oxide of iron. Talc is a hydrated silicate of magnesia; in other words, it is composed of silica, magnesia, and water. Hornblende, augite, and diallage are all silicates of magnesia, lime, and the protoxide of iron; they may or may not contain alumina, manganese, etc.; they differ from the felspars in that the alumina is to a greater or less degree replaced by iron oxides and magnesia. Olivine is a silicate of magnesia, iron, and manganese.

In the earliest period of the earth's geological history, all the rocks were igneous. Hard and indestructible as such rocks may appear to be in their unaltered state, they yet possess weaknesses of constitution which cause them eventually to succumb to the influence of atmospheric agencies, and thus to decompose and disintegrate into soft and yielding masses. As all the sedimentary or stratified rocks are derived either from igneous rocks, or from other sedimentary rocks which are traceable back to those of igneous origin, it follows that the insoluble mineral ingredients of the aqueous rocks are identical with those of the igneous rocks. It is not difficult, therefore, to trace back to the igneous rocks the materials composing the sedimentary strata. Hence it is that a study of the products of the natural decomposition of the igneous and metamorphic rocks is competent to throw a flood of light upon the constitution and the properties of the soils which it is the province of the agriculturist to cultivate.

It is possible to construct a chemical classification of rocks, that is, a grouping of rocks according to their chemical composition. Such classification, though crude, has a direct bearing upon the study of soils. *Oxides*, for example, include quartzite, sand, and the arenaceous rocks generally. *Carbonates* are exemplified in the various limestones and clay-ironstones. *Silicates* comprise the great majority of rocks, including most of the igneous and metamorphic rocks, as well as the argillaceous rocks. When, by the process of weathering, these rocks are converted into soils, it is their chemical composition rather than their mineral constitution which will determine the character of the soils which result.

Although sixty-four simple bodies, or elements, are known to chemists, yet only eleven of these enter largely into the composition of the rocks forming the crust of the earth. It is estimated that these eleven elementary substances constitute ninety-nine out of every hundred parts of the earth's crust, and their approximate relative proportions are set forth in Table VI. :—

TABLE VI.—ESTIMATED PERCENTAGE OF THE ELEMENTS OF THE EARTH'S CRUST.

A.

The simple Elements with Oxygen separate.

1.	Oxygen	50·0
2.	Silicon	25·0
3.	Aluminium	10·0
4.	Calcium	4·5
5.	Magnesium	3·5
6.	Sodium	2·0
7.	Potassium	1·6
8.–11.	Carbon, Iron, Sulphur, Chlorine	2·4
12.	Other bodies	1·0
		100·0

B.

The same with the Oxygen in combination.

I.	Silica	53·0
II.	Alumina	19·0
III.	Lime	6·3
IV.	Magnesia	5·8
V.	Soda	2·5
VI.	Potash	2·4
VII.–X.	Carbonic acid, Iron oxides, Sulphuric acid, (Chlorides)	7·5
XI.	Other bodies	3·5
		100·0

THE DECAY OF IGNEOUS ROCKS.

The most abundant of all minerals is felspar. It enters into the composition of granite, gneiss, felsite, and many other rocks. Granite is often referred to as an example of that which is firm and massive; and yet, even in such a hard rock as this is known to be, the felspar is a source of weakness rather than of strength. The reason of this is that felspar easily yields to the solvent influence of natural waters. Though water which is chemically pure is not without a solvent action upon many substances, its solvent action is greatly enhanced, and the range of soluble substances increased, if the water contains carbonic acid gas (carbon dioxide, CO_2) dissolved in it. Natural waters all contain carbonic acid, which renders them, as they percolate through rock masses, the better competent to carry away certain substances in solution, and thus to weaken the fabric of the rock. Under the influence of rain and surface waters, then, the felspars are decomposed. The lime, or potash, or soda they contain is converted into a soluble carbonate which is carried away in the water, and the silica which is set free remains mostly as an impalpable powder. But felspars contain a large proportion of silicate of alumina, and this combination of silica and alumina being quite insoluble, forms with some of the water a white mealy powder, unctuous and plastic, which is also left behind. This material is kaolin, or china-clay; it is described by chemists as a hydrated

silicate of alumina. The normal composition of pure kaolin is:—

Silica . . .	46·4
Alumina . . .	39·7
Water . . .	13·9
	100·0

As a matter of fact, however, all china-clays contain, besides the definite hydrated silicate representing the typical kaolin, small portions of other ingredients present in the original rock. The percentage of silica may thus vary in different specimens from 46 to 60; of alumina, from 26 to 40; and of water, from 7 to 14. Small quantities of lime, magnesia, potash, soda, and iron-peroxide may or may not be present.

The importance of kaolin is due to the circumstance that it forms the basis of all clays. Very pure kaolins are obtained from granite and pegmatite, and kaolin is also yielded by gneisses and porphyries.

Other mineral silicates are equally susceptible with the felspars to the decomposing influence of natural waters. As some of these other silicates constitute so large a portion of certain igneous rocks, in which free quartz is generally absent, the whole mass disintegrates and decomposes. The normal composition of some of these other silicates is seen in Table VII.:—

TABLE VII.—CHEMICAL COMPOSITION OF CERTAIN MINERAL SILICATES

	Hornblende.	Augite.	Olivine.
Silica . . .	48·8	54·1	38·5
Alumina . . .	7·5	—	0·2
Lime . . .	10·2	23·5	—
Magnesia . .	13·6	11·5	48·4
Iron protoxide .	18·75	10·0	11·2
Manganese oxide .	1·15	0·6	0·3
	100·00	99·7	98·6

Their composition shows that such rocks as these are competent to furnish not only kaolin, together with lime and magnesia, but also a large proportion of peroxide of iron, resulting from the oxidation of the protoxide, whilst a hydrated silicate of the protoxide of iron is formed as another product of the alteration of the hornblendes and the augites. Thus it is that the widely disseminated peroxides of iron and glauconite (silicate of iron), so abundant in many of the sedimentary strata, have originated. It is owing to the presence of these complex silicates, containing lime, magnesia, and the metallic oxides, that diorite, diabase, melaphyre, and other basic rocks generally decompose into green and brown clays. Great bodies of these rocks are also often converted into masses of soft and decayed rock, of green, grey, red, or brown colours, formerly known under the general name of wacké.

Claystones are altered felspathic and porphyritic rocks. Serpentine yields magnesian clays, white or coloured, sometimes containing as much as 33 per cent. of magnesia.

Basalt, like the older greenstones, contains other silicates besides felspar, so that the decomposition of the hornblende, augite, olivine, and other minerals in such rocks liberates, in addition to the silica and alumina, proportions of lime, magnesia, iron, and manganese, which variously modify and colour the clays. The red clays of the Coal-measures and other strata much resemble in their composition some of the basalt clays, and were probably derived from some similar older rocks. Table VIII., on page 26, shows the composition of one of these red clays, and of two basalt clays. The latter may be compared with the analysis of undecomposed basalt (Table III., page 17).

Other basic volcanic rocks, such as dolerite and andesite, are also liable to decompose, as, in a lesser degree,

are the trachytic lavas and scoriæ, which latter, however, give rise to light-coloured clays, sometimes as white as chalk. According to Professor Prestwich, "The village 'Bianca,' in the volcanic country near Rome, derives its name from the whiteness of the soil produced by the kaolin resulting from the decomposition of trachytic cinders, just as peperino, which is a darker tufa, results from the decomposition of the ashes and cinders of basic lavas; in both cases the decomposed mass has often been

TABLE VIII.—CHEMICAL COMPOSITION OF BASALT AND RED CLAYS.

	Basalt-clay, Annaberg.	Basalt-clay. Silesia.	Red clay. Coal measures. Broxley.
Silica . . .	40·352	53·01	64·06
Alumina . . .	32·515	14·49	20·60
Lime . . .	3·727	2·85	0·12
Magnesia . .	1·277	2·39	0·04
Potash . . .	0·365	0·19	0·91
Soda . . .	1·311	0·25	0·44
Iron peroxide . .	9·170	—	6·84
,, protoxide .	—	14·87	0·32
Manganese . .	0·034	—	0·09
Titanic acid . .	1·461	—	0·62
Water and loss .	9·646	10·65	5·85
	99 858	98·70	99·89

subsequently solidified by the infiltration of calcareous or siliceous matter in solution."

It is from the fact that all ordinary clays consist in the main of hydrated silicate of alumina, mixed with a portion of impalpable free silica, together with impurities derived from the several associated minerals in which lime, magnesia, iron, manganese, etc., are present, that their origin is traced, directly or indirectly, to the decomposition of the older volcanic and plutonic rocks.

Besides the insoluble residues set free by the decomposition of felspars and other silicates which enter into the constitution of igneous rocks, there are the dissolved materials which are carried away in the surface and underground waters. These consist partly of carbonates of potash, soda, lime, and magnesia, and partly of silica, either free or in combination. The alumina is not removed in solution, hence the apparent gain of this ingredient in the insoluble residues. This is illustrated in Table IX., showing the analyses of a Cornish greenstone (probably a dolerite) before and after natural disintegration. The third and fourth columns of figures are calculated on the assumption that the absolute quantity of alumina is the same both in the original and in the altered rock; in other words, that there has been no loss of alumina:—

TABLE IX.—CHEMICAL COMPOSITION OF A CORNISH GREENSTONE, BEFORE AND AFTER DISINTEGRATION.

	Original.	Altered.	Original.	Altered.
Alumina	15·8	22·1	100	100
Silica	51·4	44·5	325	201
Lime	5·7	1·4	36	6
Magnesia	2·8	2·7	17	12
Potash	1·6	1·2	33	13
Soda	3·9	1·7		
Iron protoxide	12·9	—	—	—
,, peroxide	2·5	17·6	106	79
Manganese oxide	0·5		3	
Water, etc.	2·4	9·6	11	38
	99·5	100·8	631	449

In this greenstone, therefore, the total loss of silica, lime, magnesia, potash, soda, iron oxide, and manganese amounted to 34 per cent. A similar comparison in the

case of a Bohemian basalt showed a corresponding loss of 44 per cent. Serpentine in the course of decomposition allows the waters to carry away a great deal of its magnesia and most of its potash and soda. The greatest loss which the igneous rocks thus undergo is of their potash and soda; then follow lime and magnesia; and next silica and iron. The silica passes off for the most part probably as a soluble silicate, and the other ingredients pass away as carbonates.

What becomes of the substances of which the igneous rocks are thus despoiled? The waters carrying these materials in solution find their way into the rivers, and thence into the sea. In that great aqueous reservoir, the lime, magnesia, silica and iron are for the most part either precipitated by chemical means, or separated from the water by the activity of living organisms. By the accumulation on the ocean floor of the remains (shells, etc.) of these organisms are produced the various limestones, oolites, and other calcareous strata, as well as the deposits of diatomaceous earths and other aggregations of remains of siliceous organisms.

As to the potash and soda, these remain dissolved in the water, save such small quantities as are taken up by sea-weeds, or they are retained in the insoluble residues of the igneous rocks by the remarkable absorbent power of alumina for these substances, especially for potash; some of the potash and soda may, on the other hand, be left in the undecomposed portion of the felspars.

It has been shown that the silicates which enter so largely into the constitution of igneous rocks decompose into certain soluble and insoluble products; the carbonates of potash, etc., being examples of the former, and kaolin an example of the latter. There remains to be considered

one other, and a very important, ingredient of igneous rocks, namely, the free silica or quartz, which is specially noteworthy in the so-called acidic rocks. Taking granite, again, as a type of this class of rocks, it consists of a mixture of quartz and felspar in about equal proportions, together with 5 to 10 per cent. of mica. By the gradual decay of the felspar in the manner which has been described the whole granite mass loses its coherence, its fabric is irretrievably weakened; and as the decomposed soft parts are gradually removed, that which is left behind crumbles down into a grit or gravel of quartz, spangled with flakes of mica. The longer this material is exposed to atmospheric agencies, the more completely are the residual fragments of felspar dissolved and washed away, and the more exclusively arenaceous or sandy does the loose mass become. Exposed to the rolling action of the waves on a beach or shore-line, the siliceous particles are still further reduced in size; their angles and corners are worn away, and there will ultimately result the finely-divided uniform gravel which is known as sand. Such sand may, of course, be carried away by rivers, and deposited on the ocean floor, where it may get consolidated and cemented into a sandstone, to be subsequently upheaved, and again exposed to disintegration and denudation, thereby giving rise to a newer and a younger sandstone. But, directly or indirectly, sand and sandstone, like clay and limestone, are traceable back to the igneous rocks. Some sandstones are very pure (quartzose), others glitter with particles of mica (micaceous), and yet others are more or less clayey, owing to their still retaining fragments of felspar (felspathic). Some of the millstone-grits of South Derbyshire are made up of a quartz grit, with a very large proportion of rolled and worn grains of felspar; and near Angoulême,

in France, a Jurassic sandstone contains so much decomposed felspar, that it is worked and washed for china-clay.

Where considerable areas of igneous rock are exposed at the earth's surface it is not uncommonly the case that these have undergone extensive decomposition and disintegration *in situ*, so that they become covered with the products of their own decay. This decay may extend downwards to a few feet only or to more than a hundred feet; and it is very irregular in character, especially in the case of granite, some parts of the rock resisting decomposition more than others (fig. 4). In Cornwall the

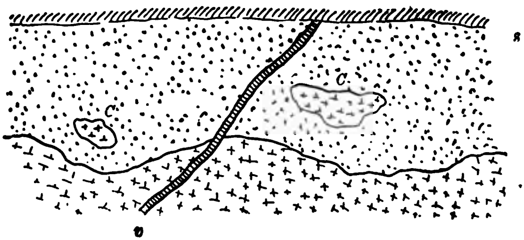

FIG. 4.—DECAY OF GRANITE IN SITU.
v, Vein of quartz. *s*, Vegetable soil. *C*, Core of granite.
b, Decomposed granite. *a*, Solid granite.

granite is so disintegrated that the country presents a surface of fine quartz grit or gravel; in Aberdeenshire it is subject to very little change. In Auvergne there are granites which have decomposed to the depth of more than 100 feet. Those portions of granitic rock which resist decomposition more than others may eventually be left exposed upon the surface; thus arise the isolated "tors" so characteristic of the scenery of Dartmoor, the Land's End, and other granite districts, whilst

"rocking stones" are due to the same cause. Popular notions as to the imperishable nature of granite are not borne out by fact; and in drift beds of very recent geological date, while fragments of sandstone and even of limestone may be found unaltered, the harder granite pebbles are sometimes thoroughly disintegrated, and fall to pieces when moved. Moisture, or even a damp condition, is the great agent in effecting the decomposition of granite. Not alone the chemical action of water, but its mechanical effect in freezing, has to be considered, and, in addition, mere changes of temperature weaken the rock, on account of the different rates of expansion of its constituent minerals.

Some gneisses decompose into more or less pure kaolin clays, as is the case in Auvergne and other parts of Central France. At Rio Janeiro the gneiss has yielded a reddish clay varying from a few inches to 100 feet deep. In Guernsey and Jersey syenites and diorites are disintegrated to a depth of 50 feet or more; and a considerable part of the north of the island of Alderney consists of a thick bed of sand and fine gravel with boulders, all derived from the decomposition of the greenstone rock *in situ*.

Serpentines and basalts are often decomposed to a considerable depth, in the former case giving rise to an unctuous clay with veins of silica and carbonate of magnesia, and in the latter to an impure ferruginous clay which may become light-coloured as the iron gets carried away in solution. Schistose rocks are sometimes covered by a depth of marl or clay which has resulted from their decay.

The great fact to grasp is—and it is well to repeat it—that all the constituents of sedimentary rocks can be

traced back to igneous rocks. The indestructible quartz forms the base of the sandstones ; the silicates, particularly those in the felspars, form the basis of all clays ; lime combined with carbonic acid affords the material of the calcareous strata.

SAND.

Sand-beds is the name given to loose aggregates of grains of quartz, often with minute plates of mica, and sometimes with green particles of glauconite. Such beds are seen in the Bagshot sands, the Thanet sands, and the sands of Reigate and Hindhead. They are frequently slightly coloured by the peroxides of iron and manganese.

Excepting, perhaps, volcanic ashes, no class of rock is so much the sport of the winds as sand. Dunes are formed by the drifting inland of the sands on exposed shores, the land-surface—with its vegetation, buildings, and farms—being overwhelmed. On the Norfolk coast the wind has formed sandhills 50 to 60 feet high, and the same is the case on the Cornwall coast. The coasts of Carnarvon and Lancashire afford other examples of the same kind, and many such are to be seen along the Irish and Scotch coast-lines. A celebrated case is that of the Landes on the coast of France, between Bordeaux and Bayonne, where the sea throws up annually 5,000,000 cubic metres of sand along a coast-line more than 100 miles in length. These dunes have an average width of three miles, and are advancing inland at the rate of about 3 to 6 feet annually. When much calcareous shell-sand is present in dunes, the percolation of rain-water with its dissolved carbonic acid cements the sand into a rock hard enough to be used as a building-stone. The rain-water alternately dissolves a little of the lime and on

evaporation re-deposits it as a thin crust cementing the grains of sand together. Sand dunes stretch for more than 200 miles along the coast of Denmark, and form hillocks from 30 to 100 feet high. The sand-dunes on the coast of Holland attain an average height of 50 to 60 feet.

The borders of large lakes and inland seas are sometimes invaded by these shifting sands. On the south-east shores of Lake Michigan sand-dunes of 100 feet to 200 feet in height have entombed large forest areas. The dunes of the eastern shores of the Caspian Sea spread across the desert region between that sea and the Sea of Aral. Vast arid wastes of loose sand exist even in the interior of continents. The immense desert of the Sahara is probably in great part a modern sea-bottom which has been upheaved and dried. Great sand wastes exist on the steppes of southern Russia and the adjacent regions. Vast deserts of sand occupy some parts of the interior of Australia. The sandy deserts of the elevated table-lands of western North America, which have never been beneath the sea for a long series of geological ages, owe their formation almost entirely to the effects of atmospheric disintegration. The sand-hills of Wyoming territory cover an area of about 20,000 square miles on both sides of the Niobrara river. The loose moving sand is blown into round dome-shaped hills, and the strong winds fill the air with a storm of sand, and throw up the surface into graceful wave-like furrows. Though the hills are barren, there is a scanty grassy vegetation in the intervals. These sandhills form but a portion of the "bad lands," the name given to considerable areas of a region which extends over portions of the States of Nebraska, Colorado, Wyoming, and Utah, between the

latitude of Santa Fé (36° N.) and that of Cheyenne ($41\frac{1}{2}$° N.), and between the meridians of 99° and 111° W.

According to the United States geologists :—

"In the arid region of the western portion of the United States, there are certain tracts of country which have received the name of *mauvaises terres*, or bad lands. These are dreary wastes—naked hills, with rounded or conical forms, composed of sand, sandy clays, or fine fragments of shaly rocks, with steep slopes; and, yielding to the pressure of the foot, they are climbed only by the greatest toil, and it is a labour of no inconsiderable magnitude to penetrate or cross such a district of country.

"The vast plains to the west of Cheyenne are covered with the drab-yellow and light-grey sands, marls, and clays of the great freshwater lake deposit, known as the 'bad lands.'"

In describing the superficial deposits of Nebraska, Aughey observes that the bad lands do not really belong to the surface deposits, as they constitute a peculiar formation, where most of the soil capable of being cultivated has been removed by denudation. They belong to what Hayden calls the White River group of Tertiary rocks, and are believed to be of Miocene age. The materials of the deposits are white and yellowish indurated clays, sands, and marls, with occasional thin beds of lime and sandstones. "The geologist never tires of investigating these deposits and their curious remains. The almost vertical sections of variously-coloured rock have been chiselled by water agencies into unique forms. Indeed, viewed from a short distance, they remind the explorer of one of those old cities which only exhibit their ruins as reminders of their ancient greatness. Among these grand desolations, the weird, wild old stories of witchery appear

plausible and possible. It is in the deep cañons at the foot of stair-like projections that the earliest of those wonderful fossil treasures are found which have done so much to revolutionize our notions of the progress of life and of Tertiary times." "Agriculture in such a region as this," it is added, "where often nothing is now growing, is, of course, out of the question. Whether there ever will be such an increased rainfall as to start vegetation in this region and make its surface capable of cultivation, is a problem of the future."

Even in the middle of England, a fine, dry sand, yielded by the weathering of the New Red Sandstone (Triassic), is sometimes heaped up into small dunes.

As a soil, pure sand alone would be useless, both physically and chemically. Consisting as it does of hard minute granules, it is necessarily very porous, and is therefore not retentive of moisture, so that a few days' sunshine would render it dry and arid. Then, again, as the particles have no mutual cohesion, they would easily become the sport of the wind, so that even supposing a plant to be growing on pure sand, it would have no grip or hold on the soil, unless it possessed very long straggling roots like those of some of the seashore grasses. From the chemical side, the objections to a soil of sand are even more serious, for it could offer the plant nothing in the shape of essential food. Yet, notwithstanding these drawbacks, sand, as a *constituent* of soils, confers on them two important properties: it renders them light, and therefore permeable to air, moisture, and warmth; and it also concentrates and stores up the solar heat.

An interesting case of a soil of almost pure sand is under consideration at the present time in the Pine Barrens of the State of Michigan, where a considerable

area is in process of reclamation. A large portion of the lands in the northern half of the lower peninsula which lies between Lake Huron and Lake Michigan, is composed of a light sand which has the reputation of being infertile. Repeated attempts to bring these lands under successful cultivation have either failed altogether or have been attended with such little success as to discourage settlement. The area involved is from 5,000 to 10,000 square miles. At present, therefore, a region as large as the cultivated portion of the Valley of the Nile, which for thousands of years has supported a population of six millions, and was for centuries the granary of the Roman empire, is left in what seems to be hopeless sterility. But, through the public enterprise of the State, steps are being taken to redeem this immense area, and to fit it for agricultural occupation. Five experimental stations have been established, and at these various trials are in progress, some of which are likely to prove successful. Two great difficulties to be met are, that frosts come late in the spring and early in the fall, and that there is but little vegetable matter in the soil. The latter has, in some localities, been burnt; in others, notably where the pine has grown almost exclusively, very little vegetable matter has accumulated. Although it has been proved that the soil responds readily to manure and other fertilizers, yet, as so large an area has to be dealt with, the first step is to find a grass that will grow in such a soil and situation, and thereby increase the fertility, both from the soil itself and from the atmosphere. Grasses, likely to prove suitable, are being introduced from all parts of the world; and if one or more species are indicated by the experimental results to be adapted to the region, they will be sown. The crop will furnish food

for stock, and the hardest part of the problem will thus be solved, as it will then be rendered possible to gradually bring the land into condition.

Sandstone is a rock consisting of consolidated sand. The colours of sandstones are due, not so much to the quartz particles of which they in the main consist, as to the film or crust which often coats these fragments and holds them together as a cement. Iron, which forms the basis of most pigments of rocks, gives rise to red, brown, yellow, and green hues, according to its degree of oxidation and hydration. Ordinary sandstones are generally soft, often friable, and permeable to water, though, when the cementing material is siliceous, they pass into hard, impermeable sandstones and quartzites. In this latter form they are distinguished as siliceous sandstones; and the "grey wethers" of Wiltshire and adjacent districts afford examples. Very siliceous sandstones with a close even grain, are called cank, cankstone, or galliard stone. If the grains of quartz are cemented together by carbonate of lime, a calcareous sandstone is the result, the Kentish Rag being an example. Sometimes grains of felspar, more or less decomposed, are interspersed through the rock, which is then called a felspathic sandstone; examples are afforded by the Millstone Grit, and by many sandstones near granitic regions. An argillaceous sandstone is one in which the quartz grains are mixed with clay, and which emits an earthy smell when breathed upon; examples occur in the Coal Measures and the New Red Sandstone. When the particles are cemented together by the peroxide of iron, a red, yellow, or brown ferruginous sandstone is the result; the carstone of Cambridgeshire and Lincolnshire, and some of the Wealden sandstones, afford examples. Green sandstones, as in the Upper Greensand,

owe their colour to the presence of grains of dark green glauconite (silicate of iron). The French name, *gaize*, has been applied to a sandstone, the matrix of which is soluble silica (so called from its being dissolved by a boiling solution of potash), which has been precipitated as an impalpable white powder; it is particularly abundant in the Upper Greensand, being present in some beds to the

TABLE X.—CHEMICAL COMPOSITION OF CERTAIN SANDSTONES.

	Red Sandstone (Bunter). Shiffnall.	Purple Sandstone (Caradoc). Horderley.	Carboniferous Sandstone. Heddon.	Magnesian Sandstone (Permian). Mansfield.	Calcareous Sandstone (Miocene). Aix-les-Bains.	Chalk-flint.
Silica	96·31	92·49	95·1	49·4	71·45	98·00
Alumina	0·80	2·47	and iron 2·3	and iron 3·2	0·25	0·25
Carbonate of Lime	0·35	—	0·8	26·5	25·15	Lime 0·50
" " Magnesia	0·75	—	—	16·1	2·50	—
Iron peroxide	1·30	3·51	—	—	0·85	0·25
" protoxide	—	1·11	—	—		
Combined water	0·65	0·42	1·8	4·8	—	1·00
	100·16	100·00	100·0	100·0	100·20	100·00

extent of from 40 to 70 per cent. Flagstones are hard sandstones which, owing to the presence of mica or other substances, split along the planes of stratification into thin beds or flags; if the mica is very noticeable, the rock is a micaceous sandstone (called "fakes" in Scotland). In a sandstone grit, the grains of quartz are larger than usual; or there may be an admixture of small pebbles, as in portions of the Millstone Grit. Conglomerates or puddingstones consist of pebbles of various sizes cemented together by a calcareous, argillaceous, siliceous, or ferruginous

matrix; examples are afforded in the conglomerates of the Old Red and New Red Sandstones, and in the Lower Tertiary puddingstones of Hertfordshire. If the included fragments are angular instead of rounded (waterworn) the rock is called a breccia; examples are seen in the Permian strata.

Superficial detrital beds of recent origin are known as loess, gravel, and shingle. Loess, or brick-earth, is a light-brown or reddish loam, sometimes enclosing small calcareous concretions called "race." The brick-earths of the Lower Thames and Medway valleys, and the loess of the Rhine, are examples. Gravel is a loose aggregation of rocky fragments, rounded or somewhat angular, imbedded in a matrix of finer material, incoherent, and derived from the same source as the larger stones. When a gravel becomes cemented into a solid rock it forms a conglomerate. Shingle is the name given to the more rounded rock-fragments found on shores and shoals.

CLAY.

Clays are described as hydrated silicates of alumina, that is, compounds of alumina, silica, and water. Alumina may, therefore, be regarded as forming the basis of all clays; and it confers upon them some of their most distinctive properties. These soft rocks may or may not also contain a variable quantity of free silica. As is well known, they have the property of becoming plastic when mixed with water, and of hardening when exposed to fire. As a matter of fact, it is the combined water which gives to clay its plasticity, for if this be driven off by heat the clay is no longer plastic. Hence, although powdered brick will absorb a great deal of water, it is impossible thereby to render it again plastic, because this absorbed water does not enter into chemical combination. The dark bluish-grey colour which so many clays possess is due to the diffusion throughout their mass of oxide or sulphide of iron, or of organic carbonaceous matter. Other colours, such as red, purple, yellow and green, arise from the presence of the peroxide and protoxide of iron. Rocks that contain clay to any appreciable extent emit a characteristic earthy smell when breathed upon. Some clays are more or less calcareous, owing to the presence of carbonate of lime. By a process of segregation roundish masses of impure carbonate of lime, called septaria, or cement-stones, arise in such clays; when broken across, the septaria reveal a mass of clayey

matter subdivided by limestone partings (septa). By a similar process crystals of the soft mineral sulphate of lime (selenite) are formed. Clay ironstone and iron pyrites may also occur as segregated masses in clayey rocks or shales.

The clays to which reference has just been made are those whose basis consists of kaolin, the origin of which has already been described. There is, however, another clayey substance, which consists of felspar reduced to a very fine powder, but not chemically decomposed. It possesses many of the characteristic properties of ordinary clay, and is so finely divided that when mixed with water it may take days for the whole of it to settle at the bottom. It is usually less plastic than kaolin, and differs from the latter in being anhydrous, that is, it contains no chemically combined water. And whereas kaolin is a simple silicate of alumina, the insoluble residue of the chemical disintegration of felspar, this felspathic mud, as it is termed, has practically the same chemical composition as felspar, having been produced by the mechanical disintegration of that mineral. Hence, argillaceous rocks may be regarded as (1) clays proper, in which kaolin predominates; (2) mudstones, in which felspathic mud predominates. In both there may be admixtures of other substances. As might be expected, there exist all kinds of gradations between kaolin on the one hand and felspathic mud on the other.

Many modifications of clay exist. Pipe-clay is a white pure clay which shrinks considerably in heating. Pot-clay is an impure china-clay which can be moulded and heated into a coarse coloured ware. Brick-clay is of a still coarser nature, the finer varieties of which, consisting of a very finely divided and intimate mixture of clay

TABLE XI.—CHEMICAL COMPOSITION OF CERTAIN CLAYS.

	EOCENE.	CRETACEOUS.	JURASSIC.	CARBONIFEROUS.		SILURIAN.	EOCENE.
	Pottery clay. Poole.	Fuller's-earth. Nutfield.	Blue clay. Wilts.	Fire clay. Stourbridge.	Red Ti e clay. Broseley.	White soapy clay. Horderley.	Pottery clay. Bovey.
Silica	48·99	57·0	55·16	73·82	64·06	45·48	47·0
Alumina	32·11	10·3	21·88	15·88	20·60	23·52	48·0
Lime	0·43	—	sulphide 2·62	traces	0·12	carbonate 11·10	—
Magnesia	0·22	3·0	1·51	,,	0·04	1·44	2·0
Potash	3·31	—	2·22	0·90	0·91	2·15	—
Soda	—	—	2·40		0·44	0·54	—
Iron protoxide	2·34	6·7	4·17	2 95	0·32	1·76	1·5
,, peroxide	—		—	—	6·84	—	
Manganese protoxide	—	—	—	—	0·09	0·07	—
Titanic acid	—	—	2·19	—	0·62	—	—
Water	11·99	23·0	7·25	6·45	5·85	18·88	1·5
	99·39	100·0	99·40	100·00	99·89	99·94	100·0

and sand, are called brick-earth. Fire clays are those which can undergo intense heat without melting. Fuller's-earth is the name given to a clay which contains such an excess of silica as, instead of being plastic, to fall to a fine powder in water. Loam is clay mixed with fine sand, the latter being present in such proportions as to permit of water percolating through the mass and to prevent its binding together. The grey or light-brown colour of many loams is due to the presence of a small quantity of peroxide of iron. Brick-earth is a good example of loam.

Shale is the name given to clay and marl more or less hardened and laminated in the plane of its deposition, and which therefore splits into layers along the planes of bedding. The shaly character is promoted by the presence of accidental minerals, such as mica, of sand, and of carbonaceous and bituminous matter; micaceous and carbonaceous shales are thus produced. The shales of the Coal Measures and of the Kimmeridge Clay are familiar examples. Miners apply to shales such terms as bind, blue-bind, plate, and shiver. If shales contain enough iron pyrites to be used for the manufacture of alum, they are called alum shales. The presence of a considerable quantity of sand constitutes sandy shale, or stone bind, or rock bind. Shales stained dark by vegetable matter are called carbonaceous shale, bass, or batt. Marl is a clay containing a considerable proportion of carbonate of lime, but yet retaining its soft plastic character. If the marl splits into plates, it is called calcareous shale, or marl slate. When it is indurated or hardened it becomes a marlstone, and crumbles to pieces on exposure to the weather. As the proportion of lime increases, the rock passes into argillaceous limestone, and then into pure limestone. The greater the proportion of carbonate of

lime present, the more soluble is the rock in dilute hydrochloric acid. Examples of marls are afforded in the Chalk Marl and the Lias Marlstone.

TABLE XII.—CHEMICAL COMPOSITION OF CERTAIN MARLS.

	Chalk-marl. Farnham.	Chloritic Chalk. Cambrai.	Kimmeridge Clay-marl. Dorset.	Jurassic. Jura.	Keuper-marl. Worcester.
Silica and clay . . .	26·05	40·965	65·72	40·2	53·62
Alumina and iron oxide	3·04	2·200		3·8	25·38
Carbonate of lime . .	66·67	56·426	34·28	52·5	7·69
,, ,, Magnesia	0·68	0·204	—	1·2*a*	5·10
Phosphoric acid . . .	1·82	0·205	—	—	2·91*b*
	98·26	100·000	100·00	97·7	94·70

a Sulphate of lime. *b* Alkalies and loss.

From a chemical point of view, pure clay would be as useless as pure sand as a source of plant food; but clays are always more or less impure, and the impurities present usually contain elements, such as potassium, iron, calcium, and magnesium, which play an important part in the nutrition of plants. The physical properties of clay are, in many cases, the reverse of those of sand. Sand is loose and incoherent, clay is firm, plastic, and tenacious; sand rapidly loses moisture, clay is very retentive of it; sand will easily become hot and dry, whereas clay remains cool, and is well able to resist a drought. It appears, then, that a soil consisting entirely of clay would be very firm, cold, and damp, and if exposed to much rain the surface would become muddy, owing to the moisture not draining away. As one of the constituents of a soil, however, clay is found to possess many valuable proper-

ties. Thus, it condenses the oxygen of the air; retains water, thereby keeping the soil moist; gives tenacity to the soil, preserves the useful products of decomposition of manures, and is rich in alkaline salts adapted to supply plants with food.

It has been stated on the preceding page that clay is firm, plastic, and tenacious. As a matter of fact, the tenacity of stiff or heavy soils arises from the presence of clay and fine silt. Clay, in its physical constitution, may be compared with glaziers' putty, the cementing or binding property of clay being due to the presence of a colloid substance (κόλλα, glue), the quantity of which probably seldom or never exceeds 2 per cent. The so-called coagulation of clay, such as is effected by frost, is attributed to the removal of water from the colloid material, as a result of which it shrinks, its cementing capacity thereby being lessened. Various chemical salts, notably salts of lime, will coagulate clay. Distilled water will hold colloid clay in suspension for an indefinite time, but it will be precipitated at once on adding a few drops of solution of a salt of lime. Similarly, by applying lime or chalk to a clay soil its tenacity is lessened and its perviousness increased, whilst it becomes more free-working. On the other hand, uncoagulated clay is sticky, scarcely permeable to water, and incapable of being brought into a condition of fine tilth.

Clay burning, in the rare cases in which it is resorted to, involves a complete loss of such nitrogen as the soil may contain. The burning is better effected at a low than at a high temperature, though at a considerable heat the lime which may be present will set free some of the potash in the insoluble silicates. After burning, the heaps are spread out on the land and ploughed in, thereby imparting to the soil a better texture.

LIMESTONE.

LIMESTONES, in their purest form, consist almost entirely of carbonate of lime. As a rule, they are impure, and often coloured by iron and organic matter. Sir A. Geikie describes them as "essentially a mass of calcium carbonate, sometimes nearly pure, and entirely, or almost entirely, soluble in hydrochloric acid, sometimes loaded with sand, clay, or other intermixture. Few rocks vary more in texture and composition. It may be a hard, flinty, close-grained mass, breaking with a splintery or conchoidal fracture; or a crystalline rock built up of fine crystals of calcite and resembling loaf-sugar in colour and texture; or a dull, earthy, friable, chalk-like deposit; or a compact, massive, finely granular rock resembling a close-grained sandstone or freestone. The colours, too, vary extensively, the most common being shades of blue-grey and cream-colour passing into white. Some limestones are highly siliceous, the calcareous matter having been accompanied with silica in the act of deposition; others are argillaceous, sandy, ferruginous, dolomitic, or bituminous."

Chalk is an earthy, nearly pure carbonate of lime, forming a soft white rock which soils the fingers; the more clayey varieties are called chalk marl. The oolitic limestones are calcareous freestones in which the carbonate of lime has the form of rounded grains, like the roe of a fish, embedded in a more or less pure calcareous matrix. Crystals and veins of calcite are often enclosed

in these rocks, and the Portland oolite contains layers of dark chert. When the grains in an oolite are as large as peas, the rock is called a pisolite, examples of which occur in the Inferior Oolite. A siliceous limestone is, as the name implies, a limestone intimately mixed with silica (soluble). It is very hard, and usually light-coloured; some of the beds of the Carboniferous Limestone are of this character. An hydraulic limestone is one into the composition of which silica and alumina (and sometimes magnesia) enter, in the proportion of from 20 to 35 per cent., yielding a lime that has the property of setting

TABLE XIII.—CHEMICAL COMPOSITION OF CERTAIN LIMESTONES.

	Chalk with Flints. Shoreham, Kent.	Portland Limestone (Shelly). Chilmark.	Hydraulic Limestone. Kimmeridge.	Great Oolite, Bath.	Magnesian Limestone. Bolsover.	Silurian Limestone.	Red Chalk. Hunstanton. Norfolk.
Carbonate of Lime . . .	98·40	79·0	75·7	94·59	51·1	44·6	82·3
" Magnesia	0·08	3·7	—	2·50	40·2	3·6	—
Silica	1·10	10·4	15·0	—	3·6	51·4	11.3
Iron and Alumina . .	0·42	2·0	8·2	1·20	1·8	—	6·4
Water and Loss . . .	—	4·2	1·1	1·71	3·3	0·4	—
	100·00	99·3	100·0	100·00	100·0	100·0	100·0

under water; the septaria of the London and Kimmeridge Clays, and some of the Lias limestones, afford examples. Dolomite, when pure, forms a light-coloured rock, consisting of a definite combination of 54 parts of carbonate of lime and 46 parts of carbonate of magnesia. When variable proportions of carbonate of magnesia are present, the rocks are termed magnesian limestones. Though not easy to distinguish from ordinary limestones, they are harder, denser, often gritty to the touch, and dissolve only slowly in dilute acids.

As a soil constituent, it is only in the pulverized state that limestone plays an important part; when in the form of gravel it behaves like other granular pieces of rock. Pulverized limestone has two useful agricultural properties: it furnishes plants with mineral manures in the phosphates and sulphates of lime and potash which are usually present as impurities, and it aids the decomposition of organic manures, such as farmyard and green manure.

COLOUR OF SOILS.—The causes of the different colours of soils may be to some extent explained by noticing how variations of colour arise in the stratified rocks. It is a matter of common observation that rocks, originally grey or blue, are changed to light yellow, red, or brown. Ochreous and sometimes blackish beds become white, and dark greens pass into browns and reds. Such changes are due to the oxidation of the metallic bases through the agency of air and moisture, and to deoxidation (or reduction) by organic matter. The grey clayey limestones or marls of the Lias, or Kimmeridge, for example, absorb moisture and become light-yellow or brown for some distance from the lines of joint and bedding. The explanation is, that almost all these argillaceous limestones owe their bluish-grey colour to the diffusion through their mass of a small quantity of iron pyrites (bisulphide of iron), or of some carbonaceous matter. Exposed to the influences of air and moisture, the bisulphide of iron is oxidized into the sulphate of the protoxide of iron (ferrous sulphate); by a further change the sulphuric acid unites with some of the earthy or alkaline bases (alumina, lime, magnesia, etc.) present, and the protoxide becomes a hydrated peroxide of iron. The rock therefore loses the dark colour, and retains only the slight tinge due to the presence of

the iron-peroxide. When the colouring is due to organic or carbonaceous matter this material gets slowly oxidized. The organic colouring matter may thus become completely destroyed, the carbonic acid which results being carried away in the percolating waters. Rich cultivated soils retain their dark colour because they are furnished with an abundant supply of organic matter.

The presence of minerals with a base of iron-protoxide, such as exists in glauconite (silicate of iron), gives some rocks a deep bright-green colour. On exposure, decomposition sets in, the silica being set free, and the iron, taking up water and an additional portion of oxygen, is converted into a hydrated peroxide. Consequently the rock loses its green colour, and passes to yellowish brown, or ferruginous, as may be seen in the soils of the Upper and Lower Greensand.

Argillaceous beds, such as the London, Kimmeridge, and Oxford Clays, generally contain concretions of iron pyrites, which, when exposed to the air, become oxidized, first into the sulphate, and then into the brown hydrated oxide. To the decomposition of another small portion of iron sulphide dispersed through such strata is due the change which commonly takes place in the London and other clays, from dark bluish-grey at depths, to a light burnt-umber-brown near the surface.

Bleached gravels, such as may be seen in the New Forest of Hampshire, owe their original light ochreous colour to the presence of peroxide of iron. The small amount of organic matter from the overlying peat or heather, carried down in the rain-water, reduces the peroxide of iron to a protoxide, which the free carbonic acid present converts into a carbonate; this salt, being soluble, is removed by the same surface waters, leaving

the upper part of the gravel colourless, sometimes quite white. Sands underlying beds of peat are often completely bleached in this way; and the same process is of common occurrence in alluvial deposits.

THE SOURCES OF LOSS AND OF GAIN TO THE SOIL.

THE soil is ever changing. It is continually losing matter, and as constantly gaining new matter. This is as true of uncultivated soils as of those which are under tillage, though in an enhanced degree of the latter. Every change of temperature that affects it, every frost that disrupts its particles, every shower of rain that soaks into its interstices, and every current of air that blows over its surface—each does its work in reducing the soil to a finer mechanical condition, whilst the waters that drain away from it are charged with particles held in suspension, and with other materials which have passed into solution.

In Table XIV. is shown the proportion (in parts by weight) of dissolved substances in 100,000 parts of different river waters.

TABLE XIV.—SUBSTANCES IN SOLUTION IN RIVER WATER.

	Dee, near Aberdeen.	Danube, near Vienna.	Rhine, near Basle.	Rhone, near Lyons.	Thames, at Ditton.	Seine, near Paris.
Carbonate of Lime	1·22	8·37	12·79	14·1	16·84	17·4
" Magnesia .	0·20	1·50	1·35	—	1·81	6·2
Sulphate of Lime . . .	0·17	0·29	1·54	1·4	4·37	8·9
" Magnesia . .	0·46	1·37	0·39	1·6	—	1·7
Chloride of Sodium, etc. .	0·96	traces	0·15	0·1	1·57	2·5
Silica, Iron, etc. . . .	0·11	0·89	0·9	1·0	2·61	1·4
Total	3·12	12·42	17·12	18·2	27·20	33·1

The quantity of material, whether in suspension or in solution, carried down by a river, will depend very largely upon the nature of the surface over which the water flows. The Dee, in Aberdeenshire, flowing over granites and slates, which are hard, contains about one-tenth the proportion of dissolved matter of the Thames or the Seine, each flowing over soft calcareous and argillaceous strata. Conversely, it may be inferred that when a stream is very muddy, it comes from soft rocks, easily worn away, and that when its waters are bright and clear, they are usually derived from harder strata, and often from igneous or metamorphic rocks.

The quantity of dissolved matter—of material quite invisible to the eye—carried away by some rivers is enormous, as is well shown in the case of the Thames. This river derives its soluble salts chiefly from the Oolites and Chalk of Gloucestershire, Oxfordshire, and Berkshire. It is calculated that the mean daily flow of water in the Thames past Kingston is 1250 million gallons, which contains 19 grains of dissolved mineral matter per gallon, representing a discharge of 1514 tons per 24 hours, or upwards of half a million tons of dissolved mineral matter in the year. About two-thirds of this is carbonate of lime. The Rhine contains a smaller proportion of carbonate of lime than the Thames; but it is a more voluminous river, and it is estimated that the carbonate of lime carried to the sea in solution in the Rhine water, in a year, would be sufficient to supply material for the shells of 332,539 millions of oysters.

River sediment contains little or no carbonate of lime (this being in solution in the water), but consists chiefly of silica, alumina, and peroxide of iron, with magnesia and organic matter. The composition of the silt of the Rhine,

the Loire, and the Nile, as shown in Table XV., will sufficiently illustrate this point.

TABLE XV.—CHEMICAL COMPOSITION OF RIVER SILT.

	Rhine.	Nile.	Loire.
Silica	55·43	55·48	74·59
Alumina	17·05	11·65	
Carbonate of lime	4·60	3·72	4·75
,, ,, magnesia	2·17	0·0	
Sulphate of lime	0·0	0·24	0·0
Potash and soda	0·0	1·03	0·22
Iron peroxide	15·65	20·21	12·05
Lime and magnesia	0·0	2·87	0·0
Organic and other matter	5·10	4·80	8·39
	100·00	100·00	100·00

Besides the physical agencies which break up the soil, the activity of living agents must also be noticed. The presence of dead and decaying organic matter—the remains of animals and plants—gives rise to an important series of organic acids which have a considerable solvent effect upon the mineral matter of the soil. The extension of the roots of plants through the soil aids in opening it up to the passage of air and water; and in many cases marked mechanical effects are produced by the growth of roots. Amongst the animal agents which help to disintegrate the soil, the common earthworm stands first; whilst the action of moles and other burrowing animals, and even of ants, is by no means insignificant. But though many agencies are at work promoting the breaking-up of the soil, there is one great agent which acts as the vehicle whereby the disintegrated soil is removed, and that is water. It is true that in some districts, and in certain circumstances, the wind is a great vehicle of transport; but, judged, by the magnitude of the work done, water is

easily pre-eminent in this respect. On sloping ground, the transporting effects of water and wind are obviously aided by the force of gravitation, which causes loose particles to continuously roll down to lower levels. In soils capable of sustaining vegetation, and particularly in all cultivated soils, the fact that the crop itself is a constant source of loss to the soil is easily proved by burning the plants and analysing the ashes, the mineral ingredients of which are found to be identical with some of the mineral substances of the soil.

But, if soils were subjected exclusively to continuous loss, they would grow less and less, and in time disappear. This, however, does not happen, because, whilst the soil is losing material on the one hand, it is gaining material on the other. The sources of gain are primarily those which exist in the rock from the disintegration of which the soil originally came into existence. In the case of a local or indigenous soil every gradation may be seen between the free-working surface-soil at the top, and the hard unweathered bed-rock at variable distances beneath. Wherever water can penetrate the rock must suffer; and when it is remembered that soil water is charged with carbonic acid and oxygen gas, and that it contains in solution organic acids, derived from the decay of plants and animals in the soil, its solvent powers will the more readily be recognised. Hence the same agent which is busily occupied in promoting the removal of the finer particles of soil is equally active in recuperating the soil from the rocky matter underlying it, or from the stones which may be incorporated with it. Consequently the soil really represents merely a transition stage between the rock which is the parent of the soil and the finely-divided or dissolved matter which is most usually carried away in the waters that

drain from the soil, or is exported from the soil in the form of crops. Like a river, the soil is always moving on, the difference between the two being only one of degree. The

TABLE XVI.—CROP RESIDUES PER ACRE.

	Lb. per Acre. Roots, or roots and stubble. Water-free.	Nitrogen.	Phosphoric Acid.	Potash.
ENGLAND (Voelcker).				
Good clover roots, 1st year	4155	100·0		
Bad " " "	1550	31·0		
Thin " " 2nd year	7026	66·0	29·5	
Good " " "	6503	65·0	27·0	
Clover roots, 1st year, mown twice	1493	24·5		
" " mown once	3622	51·5		
CONNECTICUT, U.S. (Atwater).				
Timothy-grass roots	2240	31·1	7·0	8·4
Wheat roots	658	6·4	1·5	2·6
Clover roots	1335	35·5	10·0	15·0
STORRS STATION, U.S.				
Cow peas: stubble and roots to 6 in. deep	711	10·0	2·7	5·3
" " " 3½ ft. deep	1095	14·5	2·8	6·4
Timothy and red top: stubble and roots to 6 in. deep	7606	83·7	23·8	53·5
Timothy and red top: stubble and roots 6 in. to 3ft deep	617	6·4	1·4	2·3
Timothy and red top: stubble and roots to 3 ft. deep	8223	90·1	25·2	55·8
Buckwheat: stubble and roots to 1 ft. deep	483	4·4	1·3	3·8
GERMANY (Weiske).				
Roots and stubble	Air dry			
Rye	3400	62·0	24·0	30·0
Barley	1515	22·0	11·0	9·0
Oats	2200	25·0	28·0	24·0
Wheat	2240	22·0	11·0	17·0
Red clover	6580	180·0	71·0	77·0
Buckwheat	1630	45·0	10·0	9·0
Peas	2400	53·0	14·0	11·0
Lupins	2800	58·0	13·0	16·0

soil which a field carries to-day is not identically the same as that which covered it a year ago; and though some of the same particles may still be there, many, on the other

hand, will have gone beyond recall. The remains of plants, and particularly the roots, which accumulate in the soil, are a definite source of gain, and serve to confer, especially upon the surface-soil, some important characters.

The manurial value of crop-refuse is often great. In Table XVI., page 56, are recorded the results of experiments made in England, the United States, and Germany,

TABLE XVII.—STONES, ROOTS, WATER, AND FINE SOIL IN SOIL SAMPLES.

(LB. PER ACRE TO A DEPTH OF 9 INCHES.)

Samples.	Original Soil as Sampled.	Stones, etc.	Roots, etc.	Water.	Fine soil (dry).
		Samples collected January 1, 1879.			
	lb.	lb.	lb.	lb.	lb.
1	3,642,024	800,061	10,400	769,040	2,062,523
2	3,680,139	916,012	12,741	761,757	1,989,629
3	3,647,469	894,613	8,875	762,057	1,981,924
4	3,708,726	823,638	11,816	765,204	2,108,068
5	3,771,343	1,028,125	9,529	782,051	1,951,638
6	3,735,951	983,258	16,008	778,961	1,957,724
Mean.	3,697,609	907,618	11,561	769,846	2,008,584
		Samples collected September 26, 1888.			
1	3,360,926	1,002,969	10,346	549,603	1,798,008
2	3,422,183	1,035,367	11,707	550,863	1,824,246
3	3,170,351	878,279	7,623	423,327	1,861,122
4	3,449,408	752,771	9,801	627,722	2,059,114
5	3,431,711	852,551	12,523	564,235	2,002,402
Mean.	3,366,915	904,387	10,400	543,150	1,908,978

with the object of determining the quantity of roots and stubble, and of valuable fertilising ingredients contained by these, per acre.

Additional evidence on this point is afforded in Table XVII., quoted from a paper on the history of a field newly laid down to permanent grass, contributed by Sir John

Lawes to the "Journal of the Royal Agricultural Society," 1889. This field had been in grass for nearly thirty years. The proportion of stones is decidedly high, being larger than that determined in any other surface soil of the Rothamsted experimental arable fields. The average amount of nitrogen in the 9 inches' depth of surface soil referred to in the Table was 0·2041 per cent. in 1879, and 0·2414 per cent. in 1888,—equivalent to 4,097 lb. per acre in 1879, and 4,604 lb. per acre in 1888. Taking the air-dried roots by themselves, the 11,561 lb. of roots per acre recorded for 1879 yielded 0·767 per cent. of nitrogen, equivalent to 88·3 lb. per acre; whilst the 10,400 lb. of roots per acre recorded for 1888 gave 0·75 per cent. of nitrogen, equivalent to 77·9 lb. per acre.

The intentional application, in the course of tillage, of natural manures and artificial fertilizers, is an obvious addition of material to the soil from which very significant results have ensued. The winds, which rob the surface of a dusty field, are not for ever on the side of loss, for much of the finely-divided material they carry from one place they deposit in another. Nor do the rains come, as it were, empty-handed; for rain-water, as it falls upon the land, though "soft," is by no means "pure."

RAIN AS A SOURCE OF GAIN TO THE SOIL.

THE composition of rain-water has been made the subject of very thorough research at Rothamsted, and the results have been embodied in an elaborate memoir contributed by Sir John Lawes, Dr. Gilbert, and Mr. Warington to the *Journal of the Royal Agricultural Society* (1881 and 1882). As the rain condenses and falls through the air it dissolves certain gases which are present. In rain-water collected in the country nitrogen and oxygen are the chief gases dissolved, together with a small quantity of carbonic acid and a still smaller amount of carbonate of ammonium. The rain further contains certain solid substances gathered in the course of its descent. Some of these, as the chlorides, sulphates, and nitrates of sodium, calcium, and ammonium, are dissolved by the rain; others, as particles of dust and soot, are merely mechanically held, and give to rain-water its usually dirty appearance. As a rule these various substances are present only in very minute quantity. Table XVIII. gives some interesting details concerning the composition of rain-water collected at Rothamsted. It indicates that nitrogen may occur in rain in the forms of nitrates, nitrites, ammonia, and organic matter. The carbon and nitrogen in the organic matter represent the soluble matter extracted by the rain from the organic dust with which it has come in contact

in the atmosphere, or on the surface of the collecting vessels. The mean proportion of nitrogen to carbon is 1:4·8 (0·19 to 0·90), so that the organic matter dissolved in rain is of a decidedly nitrogenous character. The chlorine of rain-water is due to the presence of common salt. It will be seen that the total solid matter dissolved in rain-water is considerably greater than the sum of the constituents mentioned in the table; the remaining matter is made up partly of sulphates, which form a large ingredient of rain-water.

TABLE XVIII.—THE MAXIMUM, MINIMUM, AND MEAN AMOUNTS OF CERTAIN CONSTITUENTS IN 69 SAMPLES OF RAIN-WATER, IN PARTS PER MILLION.

	Total Solid Matter.	Carbon in Organic Matter.	Nitrogen as				Chlorine.	Hardness.
			Organic Matter.	Ammonia.	Nitrates and Nitrites.	Total Nitrogen.		
Highest proportion	85·8	3·72	0·66	1·28	0·44	1·94	16·5	16·0
Lowest proportion	6·2	0·21	0·03	0·04	0·01	0·13	0·0	0·0
Mean, 69 samples	33·1	0·90	0·19	0·37	0·14*	0·70	3·1	4·7

* The mean of 34 samples.

Inasmuch as dew and hoar-frost are also sources of soil-moisture, the composition of several samples, likewise collected at Rothamsted, is given in Table XIX. The figures recorded serve to indicate that these small deposits, condensed from the lower stratum of the atmosphere, contain on an average three or four times the amount of organic carbon, organic nitrogen, ammonia, and nitric acid, found in the analyses of rain-water. The total quantity of solid matter, and the amount of chlorides, is also larger, but the difference is much smaller than in the case of the

other ingredients. The mean proportion of organic nitrogen to carbon is 1 : 3·5.

TABLE XIX.—THE MAXIMUM, MINIMUM, AND MEAN AMOUNTS OF CERTAIN CONSTITUENTS IN SEVEN SAMPLES OF DEW AND HOAR FROST, IN PARTS PER MILLION.

	Total Solid Matter.	Carbon in Organic Matter.	Nitrogen as Organic Matter.	Nitrogen as Ammonia.	Nitrogen as Nitrates and Nitrites.	Total Nitrogen.	Chlorine.	Hardness.
Highest proportion	80·0	4·50	1·96	2·31	0·50	4·55	8·0	25·0
Lowest proportion	26·4	1·95	0·26	1·07	0·28	1·66	3·5	13·0
Mean, 7 samples	48·7	2·64	0·76	1·63	0·40*	2·79	5·3	19·0

* Mean of 4 analyses.

How variable may be the composition of rain-water in different districts, is shown by the results given in Table XX., quoted from Dr. Angus Smith's "Air and Rain."

TABLE XX.—AVERAGE COMPOSITION OF SAMPLES OF RAIN FROM VARIOUS DISTRICTS OF ENGLAND AND SCOTLAND, IN PARTS PER MILLION.

District.	Nitrogen as Ammonia.	Nitrogen as Nitric Acid.	Chlorine.	Sulphuric Acid.
England, country places, inland	0·88	0·19	8·88	5·52
„ towns	4·25	0·22	8·46	34·27
Scotland, country places, sea-coast	0·61	0·11	12·24	5·64
„ „ „ inland	0·44	0·08	3·28	2·06
„ towns	3·15	0·30	5·70	16·50
„ Glasgow	7·49	0·63	8·72	70·19

The rain of towns exhibits a large increase both in ammonia and sulphuric acid, and a smaller, though a considerable, increase in chlorides and nitrates. Chlorides reach their maximum in the rain collected at the sea-coast. Rain

gathered at Valentia, on the west coast of Ireland, yielded as much as 47·35 parts of chlorine per million.

The quantities of ammonia and nitric acid supplied to the soil in rain in the course of a year have been determined in various parts of Europe. Table XXI. shows the

TABLE XXI.—DETERMINATIONS OF THE QUANTITY OF NITROGEN SUPPLIED BY RAIN, AS AMMONIA AND NITRIC ACID, TO AN ACRE OF LAND, DURING ONE YEAR.

	Rainfall.	Nitrogen per Million, as		Total Nitrogen per Acre.
		Ammonia.	Nitric Acid.	
	Inches.			lb.
Kuschen, 1864–5	11·85	0·54	0·16	1·86
„ 1865–6	17·70	0·44	0·16	2·50
Insterburg, 1864–5 . . .	27·55	0·55	0·30	5·49
„ 1865–6 . . .	23·79	0·76	0·49	6·81
Dahme, 1865	17·09	1·42	0·30	6·66
Regenwalde, 1864–5 . .	23·48	2·03	0·80	15·09
„ 1865–6 . .	19·31	1·88	0·48	10·38
„ 1866–7 . .	25·37	2·28	0·56	16·44
Ida-Marienhütte, mean of six years, 1865–70 . .	22·65	—	—	9·92
Proskau, 1864–5	17·81	3·21	1·73	20·91
Florence, 1870	36·55	1·17	0·44	13·36
„ 1871	42·48	0·81	0·22	9·89
„ 1872	50·82	0·82	0·26	12·51
Vallombrosa, 1872 . . .	79·83	0·42	0·15	10·38
Montsouris, Paris, 1877–8	23·62	1·91	0·24	11·54
„ „ 1878–9	25·79	1·20	0·70	11·16
„ „ 1879–80	15·70	1·36	1·60	10·52
Mean of 22 years . . .	27·03	—	—	10·23

results of twenty-two determinations, each extending over a whole year, and made at nine different stations. Whilst the total nitrogen supplied in the annual rainfall at Rothamsted is probably 4 to 5 lb. per acre, excluding the condensation by the soil, the mean of continental estimates, including localities near towns, is seen to be 10·23 lb. per acre.

DRAINAGE WATERS AS A SOURCE OF LOSS TO THE SOIL.

A COMPARISON of the composition of the water which falls upon a soil with that of the water which drains from the soil should afford much information respecting the ingredients which are washed out of the soil in the drainage waters. The substances thus dissolved by rain comprise: (1) those which are freely diffusible within the soil, (2) those for which the soil exercises more or less attraction, and which are therefore not freely diffusible. The freely diffusible acids are hydrochloric, nitric, and to a less extent sulphuric acid. The most readily diffusible bases are soda and lime. The combinations of these, that is, the chlorides and nitrates of sodium and calcium (lime), and, to a less extent, the sulphates are thus readily diffusible salts, and may easily be extracted from a soil if sufficient water be passed through it. On the other hand, most fertile soils possess a great retentive power for phosphoric acid, ammonia, and potash, and these substances are consequently only found in drainage waters in minute quantity, except in very special circumstances. In the case of such substances the small solvent action of rain results rather in their more equable distribution throughout a limited area of soil than in their removal from it.

In the Rothamsted experiments it has been demonstrated that the expulsion of the diffusible salts from a soil is effected most readily when the percolation is

rapid; that consequently a heavy rainfall, occurring in a few days, is far more dangerous in this respect than the same rainfall spread over a month. It is further proved that, but for the action of diffusion, and other causes tending in the same direction, the soluble salts contained in a soil would descend on the application of rain in a well-defined band, and be suddenly discharged in the drainage water; whereas the diffusion which is always taking place in a moist soil tends to distribute the chlorides and nitrates equally throughout the mass of the soil, and thus produces a considerable uniformity in the composition of the drainage water.

The richness of drainage waters in nitrates is, in our climate, greatest in early autumn, whilst it diminishes through the winter, and is least in spring. The summer is, nevertheless, the season when nitrification is most rapid, and when nitrates are most abundantly produced in the surface soil; but, as little drainage occurs in summer time, owing to the high rate of evaporation, the nitrates at that season accumulate in the soil. As the autumn advances drainage becomes active, and the washing out of the nitrates commences; the first drainage is not, however, always the strongest, because the nitrates are most abundant at the surface, and must be displaced by rain, and allowed time for diffusion, before they can appear in quantity in the drainage water. Shallow soils are most quickly washed out, whilst deep soils, possessing a larger mass for the diffusion of the nitrates, part with them more slowly and uniformly.

At Rothamsted, drain-gauges have been constructed in the soil, with the object of facilitating the collection of all the drainage waters. Three of these gauges each occupy a surface area of 6 feet by $7\frac{1}{4}$ feet ($\frac{1}{1000}$ of

an acre), but the depths of soil included in them are, respectively, 20 inches, 40 inches, and 60 inches. The quantity of nitrogen as nitrates, and of chlorine as chlorides, removed by the drainage waters from an acre of soil during each of the three drainage years named is set forth in table XXII.

It is fortunate for the sake of comparison that these three years include some widely different seasons. The year 1879–80 was one in which the drainage was rather

TABLE XXII.—AMOUNTS PER ACRE OF NITROGEN AS NITRATES AND OF CHLORINE AS CHLORIDES, CONTAINED IN THE DRAINAGE-WATER FROM THREE DRAIN-GAUGES OF DIFFERENT DEPTHS IN THREE DRAINAGE YEARS (OCT. TO SEPT.).

	20-inch Drain-Gauge.			40-inch Drain-Gauge.			60-inch Drain-Gauge.		
Year.	Drainage. Inches.	Nitrogen lb. per Acre.	Chlorine lb. per Acre.	Drainage. Inches.	Nitrogen lb. per Acre.	Chlorine lb. per Acre.	Drainage. Inches.	Nitrogen lb. per Acre.	Chlorine lb. per Acre.
1879–80	9·743	39·78	8·13	10·326	27·44	8·94	9·534	28·11	7·49
1877–78	14·591	43·87	15·31	16·605	38·95	17·74	15·784	45·45	15·65
1878–79	26·772	62·27	20·30	26·907	48·29	21·55	25·186	63·29	19·96
Mean	17·035	48·64	14·58	17·946	38·23	16·08	16·774	45·62	14·36

below the normal quantity, whilst in 1878–9 the drainage was more than twice the normal quantity. Table XXII. shows that an increase in the amount of drainage is accompanied by an increase in the amount of nitrates removed from the soil, though the latter does not increase at the same rate as the former. On the other hand, the increase in the quantity of chlorides removed from the soil is at nearly the same rate as the increase in the drainage. Expressing numerically the average results of the three gauges, the increase of the drainage in these two extreme seasons was from 100 to 268, the increase of

chlorides from 100 to 252, and the increase of nitrates from 100 to 182. As the rain which produces the increased drainage also supplies the chlorides, it is easy to understand why both drainage and chlorides should increase at a similar rate. The rain, on the other hand, supplies but an insignificant amount of nitrates, and only up to a certain point increases the rate of nitrification in the soil; the larger amount of nitrates removed by heavy rain is thus in great measure simply due to the more thorough washing of the soil.

The annual amount of nitrogen in the form of nitrates, removed in the drainage water was, on an average of 4 years (1877 to 1881), 45·51 lb., 36·32 lb., and 43·59 lb., respectively from the three drain-gauges, the mean of all being 41·81 lb., equivalent to 268 lb. of ordinary nitrate of soda. Supposing that the drainage-water contained at the same time 0·5 part of nitrogen per million in the form of organic nitrogen and ammonia, this gives a total of 43·77 lb. as the quantity of nitrogen removed in one year from an acre of uncropped soil for 17·281 inches of drainage. Such a quantity of nitrogen is equal to that contained in an average crop of wheat or barley; its loss to the soil in the drainage-water is thus a matter of grave importance. Though such loss may be, and probably is, considerably less in an ordinary agricultural fallow, occurring in rotation, than in the Rothamsted drain-gauge experiments, the loss must clearly be a very serious one whenever the season is wet. Bare fallow can only be thoroughly successful in a dry climate. In such circumstances the active production of nitrates which takes place in a fallow will doubtless greatly increase the fertility of the soil for the succeeding crop. In a wet climate the practice of bare fallow must result in a rapid diminution

of soil nitrogen. One method by which a crop will greatly diminish such loss has already been noticed, namely, by largely increasing the amount of evaporation, and thus diminishing the amount of drainage.

Besides the investigations into the composition of the drainage-waters passing from bare fallows, those yielded by land variously manured and cropped with wheat, have also been made the subject of inquiry at Rothamsted. It is desirable to bear in mind that the drainage-water passing through a natural soil is of two kinds: (1) surface-water passing downwards through open channels, (2) the discharge from the saturated soil. The first is much the poorer in dissolved ingredients, excepting when soluble manures have been recently applied to the surface. In Broadbalk field at Rothamsted, nearly twelve acres were set apart for the experiment. Drain-pipes of the "horseshoe and sole" pattern, with an internal diameter of about two inches, were laid down at depths of from two feet to two and a half feet, and at distances of eight and a quarter yards apart. The recorded observations show that whilst the deep drains employed on heavy clay land usually run uninterruptedly through the winter, the drains in Broadbalk field continue running only a few hours after rain has ceased. The cause of the difference is to be sought in the fact that the Broadbalk drains are comparatively near the surface, and that any accumulation of subsoil water is prevented by the chalk which underlies the soil at a depth of about ten to fourteen feet from the surface. The drainage-waters in Broadbalk field are thus a discharge of the water percolating through the soil, while the drainage from the deep drains in heavy land is mainly supplied from a reservoir of subsoil water.

It will be useful to point out why, in the study of

drainage-waters, special attention is given to chlorine, notwithstanding that it is an element of not much agricultural importance. The wheat crops in Broadbalk field assimilate very little of the chlorides applied (as muriate of ammonia) in the manure; in the grain practically no chlorine is found; in the straw only a small and variable quantity. Regarded simply as plant-food, therefore, chlorides merit little consideration. Yet in studying this problem of the drainage-waters, the chlorides assume a special importance. Chlorides in fact resemble nitrates in that both are salts for which soils possess apparently no chemical retentive power; they are held by the soil merely as in a sponge, and their distribution in the soil is thus regulated by the amount of rain falling on the surface, and by the ordinary laws of diffusion. As the quantity of chlorine applied in the manure to each plot in the field was, excepting in the case of the farmyard manure plot, well known, the proportion of chlorine contained in the drainage-waters becomes an excellent indication of the extent to which the soluble constituents of the manure have been washed out of the surface soil; it affords a means of judging of the relative concentration of the water issuing from different pipes, and it also serves to indicate in certain cases whether a mixture of the drainage-waters has taken place. Facts established with regard to chlorides will be equally true of the other soluble diffusible salts present in the soil.

The evidence which the drainage-waters of Broadbalk afford, both as to the production of nitrates in the soil and their removal from it by drainage, is of great practical importance. As wheat was the crop grown in the field, it is necessary to remember that the nitrates of the soil (as distinguished from other possible sources of nitrogen,

such as the atmosphere) furnish the chief, if not the only, supply of nitrogen available to the wheat crop. The drainage-waters from unmanured soil, kept free from weeds, yielded during a period of four years an average of 10·7 parts of nitrogen, as nitric acid, per million of water. With land growing wheat year after year, the result is very different. The average figures for three years show that the permanently unmanured plot yielded only 3·9 parts of nitrogen, as nitric acid, per million of water, whilst the plot receiving ash constituents alone yielded 4·3 parts, and another unmanured plot 4·5 parts. This much lower proportion of nitrates in the drainage-waters is doubtless partly owing to the great exhaustion of the nitrogen of the soil by continuous wheat cropping without manure, but is chiefly due to the fact that the crop actively appropriates the nitrates formed in the soil. So complete is this appropriation of nitrates by the wheat crop that, during the time of active growth, and for some time after, no nitric acid, or a trace only, could be found in the drainage-water from several of the plots in the field.

Some of the plots upon which wheat was continuously grown, year after year, received annual dressings of ammonium salts, consisting of equal portions of the sulphate and muriate (chloride) of ammonia of commerce. The results yielded by the drainage-waters of these plots are full of interest. Soil, as is well known, has a wonderful retentive power for ammonia, this being one reason why ammonia is so seldom present in drainage-waters. Most of the analyses showed ammonia to be present in less quantity than it is contained in ordinary rain-water. But there was an instructive exception, when ammonia was found in the drainage-water in considerable quantity The usual dressing of 400 lb. of ammonium salts per acre

was applied on October 25th, 1880, and the manure ploughed in. Heavy rain fell during the night of the 26th, so that on the morning of the 27th the drain-pipes of nearly all the plots were found running. The water collected from the ammonium-salts plot at 6.30 a.m. contained nitrogen in the form of ammonia, equal to 9·0 per million; a later collection at 1 p.m. contained 6·5 per million. Rain continuing, water was also collected on the two following days. On the 28th the water collected at 6.30 a.m. contained 2·5 per million of nitrogen as ammonia. On the 29th, at 10.30 a.m., the quantity was 1·5 per million. Ammonia is absorbed by soil, from a solution of salts of ammonium, only when the soil contains a sufficient quantity of some base capable of uniting with the acids of these salts. The Rothamsted soil contains but little chalk (carbonate of lime); it was clearly unable to decompose the ammonium-salts sufficiently quickly to prevent loss of ammonia through the heavy rain which followed so closely upon the application of the dressing.

Notwithstanding the exceptional case which has just been quoted, it is evident that normally the first result of the application of ammonium-salts to the Rothamsted soil is the chemical absorption of the ammonia; the acids of the ammonium-salts at the same time unite with the lime in the soil, and may be removed in the drainage water. Thus the water mentioned above, as containing 9·0 parts of nitrogen as ammonia, contained 146·4 parts of chlorine derived from the ammonium-salts. The speed with which nitrification of the absorbed ammonia progresses is largely dependent on the amount of rain which falls after the ammonium-salts have been applied to the soil; water is required in the first place for the solution and distribution of the ammonium-salt, and afterwards for the process of

nitrification. In consequence of the rapid nitrification of ammonium-salts, drainage-waters from plots receiving ammonia are richest in nitrates shortly after the ammonium-salts have been applied. When ammonium-salts are put on in March, the drainage-waters of April are those strongest in nitrates. Indeed, the average loss of nitrogen as nitrates in the April waters is equivalent to 6·7 lb. per acre, or,—as 1 lb. of nitrogen is contained in 6·4 lb. of good nitrate of soda,—to 42·8 lb. of nitrate of soda for each inch of drainage. When the wheat-crop commences its active growth, the quantity of nitric acid in the drainage-water rapidly diminishes; and in the case of some of the plots receiving ammonia, the nitrates disappear altogether in summer time.

To what extent the loss of nitrogen in drainage-waters is associated with the presence or absence of certain of the essential ingredients of mineral manures is shown in the results afforded by certain plots, which, whilst they all received the same quantity both of nitrogen and chlorine, received at the same time different supplies of ash constituents. Where the principal ash constituents (phosphorus, potash) required by the crop are supplied, a large assimilation of nitrogen takes place during the summer months, and the proportion of nitrogen to chlorine in the drainage-water becomes very low. Where potash has never been applied, or not for many years, a larger proportion of nitric acid escapes assimilation. Where neither phosphoric acid nor potash is applied, the proportion of nitric acid left untouched by the crop and removed in the drainage-water is much increased. In winter time, the proportion of nitrogen to chlorine in the drainage-water is in all cases high, the chlorides of the manure having by this time been washed out of the soil to a considerable

extent, while a new formation of nitric acid is continually in progress. These details are all set forth in Table XXIII., which shows the manurial treatment of each of the seven plots concerned.

TABLE XXIII.—PROPORTION OF NITROGEN AS NITRIC ACID TO 100 OF CHLORINE IN DRAINAGE WATERS FROM BROADBALK FIELD AT DIFFERENT SEASONS OF THE YEAR: AVERAGE OF THREE YEARS.

Ash Constituents applied.	Spring.	Summer.	Autumn.	Winter.	Whole Year.
Phosphoric Acid, Potash, Magnesia, Soda . . .	81·1	6·9	20·2	45·1	29·4
Ditto	30·3	6·9	18·1	43·9	27·8
Phosphoric Acid, Potash .	81·1	6·3	14·4	44·2	26·1
Phosphoric Acid, Magnesia	32·1	10·8	17·3	53·4	30·7
Phosphoric Acid, Soda. .	33·2	12·1	18·0	51·1	30·6
Phosphate alone	43·8	18·3	19·5	51·2	34·4
None	43·6	38·7	37·6	53·1	44·0

The following practical conclusions arrived at by the Rothamsted investigators, as the result of elaborate and prolonged research, are of the highest interest and importance :—

(1) Most of the nitrogen of farm-crops is derived from the nitric acid of nitrates within the soil.

(2) The nitric acid in the soil is produced from the nitrogenous compounds of the soil itself, from the nitrogenous organic matter of animal and vegetable manures, from the ammonia of artificial manures, and from the ammonia supplied by rain and condensation from the atmosphere. A very small quantity of ready-formed nitric acid is supplied by rain and condensation from the atmosphere. Nitric acid is also provided by the direct application of nitrates.

(3) The ammonia of ammonium-salts is rapidly converted into nitric acid in the soil, as also is the nitrogen

of some organic matters, such as urine. The nitrogen of rape-cake, that of the less soluble parts of farmyard manure, of stubble, of roots, etc., is much more gradually converted into nitric acid, and it may require many years for the conversion of the whole of it. The nitrogenous compounds of the soil itself are very slowly converted into nitric acid, but the soil yields a certain quantity every year.

(4) When there is no vegetation, and there is drainage from the land, or even when there is vegetation, and excess of drainage, nitric acid is lost by drainage.

(5) In the case of permanent grass-land, as the soil is always covered with vegetation, there will be with it the maximum amount of nitric acid utilized by the crop, and the minimum amount lost by drainage. Land without vegetation will be subject to the maximum loss of nitric acid by drainage.

(6) The power of a growing crop to utilize the nitric acid in the soil is much diminished if there be a deficiency of available mineral constituents, and especially of potash and phosphoric acid, within the reach of the roots.

(7) As the various crops grown upon a farm differ very much as to the period of the year of their most active growth, the length of time they remain on the land, and the character and the range of their roots, their capacity for taking up nitric acid from the soil is very different.

(8) The recognised exhausting character of corn crops is largely due to the limited season of their actual growth, and the long period during which the land is bare, or yielding little growth, and so subject to loss of nitric acid by drainage.

(9) When salts of ammonium, or nitrates, are applied as manure, the chief, if not the only, unexhausted residue of

nitrogen left within the soil available for future crops is that in the increased roots and other residues of the crops; and this is only slowly available.

(10) When oilcakes or other foods are consumed by stock, the formation of nitric acid from the manure produced is slower, but continues longer than when salts of ammonium are used. When there is a liberal use of animal manures, an accumulation of nitrogenous and mineral matter takes place in the soil, and such accumulation is known under the term "condition." Under such circumstances, the fertility of the soil is maintained, or it may even be considerably increased.

It should be added to the foregoing summary that, in a paper on the question of the fixation of free nitrogen, communicated by Sir John Lawes and Professor Gilbert to the Royal Society in the early part of the year 1890, it was stated that although chlorophyllous (*i.e.* green) plants might not directly utilize the free nitrogen of the air, some of them, such as the Papilionaceæ (clover, vetches, sainfoin, lucerne, peas, beans, etc.), may acquire nitrogen brought into combination under the influence of lower organisms, the development of which is, apparently, in some cases a coincident of the growth of the higher plant whose nutrition they are to serve. It thus appears probable that certain micro-organisms of the soil may act as carriers of nitrogen to leguminous plants from the vast stores of this element existing in the atmosphere. The nodules which are to be seen on the roots and root-fibres of clovers and their allies are associated with the development and activity of these micro-organisms.

THE MOISTURE OF THE SOIL.

Several investigations have been made at Rothamsted on the subject of the evaporation of water by plants, both when grown in pots and in the field. Calculations as to the quantity of water removed from the soil, during the hot and dry summer of 1870, served to show that a crop of manured hay of $29\frac{1}{2}$ cwt. per acre had removed from the soil at least two inches, and another manured crop of $56\frac{1}{4}$ cwt. at least 3·2 inches more water than an unmanured crop of $5\frac{3}{4}$ cwt. In the case of a crop of barley, there was apparently removed from the soil about nine inches more water than had evaporated from the adjoining bare fallow. This circumstance, that more water is lost by land covered with a crop than by the same land in a state of bare fallow, is of much interest, as exposing the incorrectness of the popular idea that soil sheltered by a crop is kept moister than a bare soil. So far as surface moisture is concerned, this may be true, but none the less does the cropped land give up the more moisture. The powerful action of a crop, in evaporating water from a soil, is mainly due to the rapid transpiration of water through the leaves, which takes place in a growing plant under the influence of light. As the roots assist by enabling the plant to take up water from depths too great to be disturbed by ordinary capillary attraction, it follows that a deep-rooted crop, such as sainfoin or lucerne, may be more effective in drying the soil than a shallow-rooted crop, such as barley.

Since the transpiration (*i.e.* evaporation from the leaf surfaces) of water by a plant is dependent on light, the amount of transpiration must be connected with the rate of assimilation and growth. When the supply of water and of soluble plant food is fairly constant, the relation between transpiration and growth will be approximately regular. From experiments made at Rothamsted upon plants grown in pots, it was concluded that from 250 to 300 lb. of water were evaporated for 1 lb. of dry matter added to the plant. But, from a soil poor in plant-food, a larger amount of water would probably need to pass through the crop, than from a well-manured soil, in order to result in the same amount of assimilation. Hence, the relation between transpiration and assimilation is likely to differ according to the circumstances. The annual evaporation from a cropped soil can, however, never be reckoned as a fixed or constant quantity, even under a uniform course of cropping, as the character of the season greatly affects the growth of the crop, and consequently its evaporating power.

The tillage of land carrying fallow crops is commonly regarded as having for its chief object the suppression of weeds. It is doubtful, however, whether its effect in the conservation of soil moisture—at all events, in seasons of drought—is not a more important and a more valuable result. In dry weather water escapes from the upper layers of the soil into the atmosphere in two ways—by transpiration and by evaporation. In the former case, it is taken up by the roots of plants and exhaled through the leaves; in the latter case, the action of the sun and wind causes water vapour to rise directly from the surface of the soil. The water which is transpired passes through the plant, conveying nutriment to it,

and is therefore of the greatest use to the farmer. That which evaporates from the soil is practically lost to him. Experiments made at the Storrs Agricultural Station illustrate very forcibly the influence of tillage upon soil moisture. Cans 30 inches deep and 10 inches in diameter were filled with soil and buried in the ground, so that the surface of the soil in the can was at the same level as that of the surrounding land. They were arranged in two lots of four cans each. Lot 1 contained garden soil, the lower 20 inches being a yellow clay loam of nearly uniform texture, and the upper 10 inches a rich heavy loam. In Lot 2 upland soil was used: the bottom 10 inches nearly pure sand; the middle 10 inches porous, light loam; the upper 10 inches filled with soil from the first 5 inches below the sod—a light loam, apparently containing a small percentage of organic matter. The experiment was commenced on July 31st, but heavy rains at first interfered. The last fortnight of August was, however, dry and warm enough to show differential results, though it was by no means a period of drought. In some of the cans the surface was not stirred at all; in others it was stirred to a depth of 2 inches, or 4 inches, every alternate day, unless rain prevented. Table XXIV. shows that, both with the heavy soil and with the light soil, there was a greater loss of moisture by evaporation

TABLE XXIV.—LOSS OF SOIL-WATER BY EVAPORATION (FROM AUGUST 15TH TO AUGUST 31ST).

Condition of Surface.	Lot I. Hvy. Soil.	Lot II. Light Soil.	Lot I. Hvy. Soil.	Lot II. Light Soil.
	lb. oz.	lb. oz.	Inches.	Inches.
Not Stirred . . .	4 13·0	3 5·0	1·69	1·16
Not Stirred . . .	4 9·0	4 2·5	1·62	1·46
Stirred 2 inches . .	3 10·5	1 12·5	1·29	0·62
Stirred 4 inches . .	3 8·0	2 3·0	1·23	0·77

from the undisturbed soil than from that which was periodically stirred at the surface. In fact, although the weather during the latter half of August was neither particularly warm nor dry, the heavy soil lost 0·4 inch less water, and the light soil 0·6 inch less, by evaporation when stirred at the surface than when not stirred.

The interpretation of these figures touches upon a point of high practical interest. It is not simply with the result of killing weeds that a farmer hoes his crops. Weeds are bad, but drought is worse, and the moisture is often insufficient for a full yield of crop, even when no drought is apparent. The soil has reserve stores of water, but in summer even this supply gets low, and the same force of capillarity which brings it up to the roots of the plants, carries it past them to the surface, where the sun's heat changes it to vapour, and the winds lick it up and bear it away. Hoeing and cultivating serve to loosen the upper layer of the soil. The capillary tubes through which the soil-water is conveyed upwards are thereby enlarged, or their continuity is severed; the capillary action is thus hindered, and less water passes to the surface. At the same time more air enters, and the loosened top layer of soil transmits less heat to the soil beneath. The loosened surface acts, in fact, as a mulch, and tends to keep the under soil cooler, whilst it prevents the water from reaching the surface, and thereby, in a twofold manner, shields the rising moisture from loss by evaporation. Thus it is that the cultivator of the soil can utilize the forces of nature in bringing water to the roots of his plants for their sustentation, and at the same time in preventing it from passing by them, and escaping as vapour into the air.

At the New York station at Geneva experiments have

been made to determine—(1) how far the amounts of moisture in the portion of the soil occupied by the roots of crops may be influenced by treatment apart from artificial watering; (2) what depth of surface tillage retains the greatest amount of soil moisture; (3) the effects of mulching compared with those of tillage in retaining soil moisture. The mulch was of fine oat straw, that had served during the preceding winter in the rearing of strawberries. A plot occupying one-twentieth of an acre was divided into ten equal parts, situated and treated as shown in the diagram :—

No 1. Surface neither mulched nor tilled. A	No. 2. Surface stirred ½ inch deep. B	No. 3. Surface stirred 2 inches deep. C	No. 4. Surface stirred 4 inches deep. D	No. 5. Surface mulched with short oat-straw 1 inch deep. E
No. 6. Like No. 5. E	No. 7. Like No. 4. D	No. 8. Like No. 3. C	No. 9. Like No. 2. B	No. 10. Like No. 1. A

This soil is, for the first 9 inches or 10 inches a clay loam, with sufficient clay to make it bake somewhat in dry weather; below, it is a very tenacious clay. The tillage on plots 2, 3, 4, and 7, 8, 9, was, after every fall of rain sufficient to puddle the surface, repeated as soon as the soil was dry enough to work. On plots 2 and 9 the garden-rake only was used. On the other tilled plots the soil was thoroughly loosened with the fork to the required

depth, after which the surface was made fine and level with the rake. Suitable arrangements were made for taking weekly samples of the soils to the depth of a foot and estimating the moisture. It was found that, with very few exceptions, the plots neither mulched nor stirred (1 and 10) contained the least moisture, while the moisture increased regularly with the depth of the stirring, and was greatest of all in the mulched plots (5 and 6).

The influence of surface treatment is of most importance in time of drought. In periods of abundant rainfall it matters little to the farmer whether soil stirred ½ inch deep or 4 inches deep contains the more moisture. The actual figures recorded in the experiment show that the amount of water retained in the soil in dry weather, by even a very shallow stirring of the surface, is by no means inconsiderable, the reason being that the capillary tubes connecting the surface with the depths are interrupted and broken. There was more water retained by the first ½ inch of stirring than by any deeper ½ inch, and this would appear to indicate that there is a limit to the depth of profitable cultivation. So long as the benefit to the crop through the conservation of moisture is greater than the injury accruing from root laceration, the cultivation is profitable; beyond this it may become unprofitable.

The depth of the mulch employed did not exceed 1 inch after it had become packed a little by the rains, and it was not renewed throughout the season. During dry weather its efficacy in retaining water was almost double that of the deepest soil-stirring resorted to in the experiment, a circumstance which emphasizes the great value of mulching. Practical men do not need to be reminded how very useful mulching is to young trees during hot summer weather.

The conclusions, therefore, are—(1) That keeping the

surface of the soil stirred, if only to the depth of $\frac{1}{2}$ inch, increases the water content of the first 12 inches to a very appreciable degree; (2) that the deeper the tillage, at least up to 4 inches, the greater is the increase in water content; (3) that the rate of increase diminishes as the depth increases; (4) that a slight mulch exerts a far greater influence in retaining water than tillage 4 inches deep.

It is noteworthy that the evaporation from a soil saturated with water exceeds that from an unbroken surface of water. In ordinary circumstances that soil will dry the quickest which has the coarsest particles and the most open texture. The water-retaining capacity of such a soil may be improved by increasing the amount of humus contained in it.

THE TEMPERATURE OF THE SOIL.

THE physical effect of farmyard manure upon soils is equally important with its chemical influence. The general rule according to which short and well-rotted dung is applied to light open soils, and long fresh dung to heavy compact soils, is one intimately associated with the mutual physical relations of soil and manure. The fresher the dung, the less ready are its constituents to enter into combinations available as plant food; and in this form a stiff clay soil is well adapted to hold or retain it till the occurrence of those chemical reactions which result in rendering the nutrient ingredients of the manure presentable to the plant. The older and the more rotted the dung before application, the more promptly are its fertilizing ingredients available; and, as light, porous soils are deficient in retentive power, it is well they should receive dung in an advanced state of decomposition, and at a time when the crop is ready to make use of it, loss of manurial substance by means of the drainage waters being thus avoided. Furthermore, long or green manure helps to open up stiff soils; and the fresh straw provides air channels along which the atmosphere can find its way into the recesses of the soil, oxidation being thereby promoted. Conversely, the application of short or much decomposed dung to a light or sandy soil has the beneficial effect of promoting its consolidation and of rendering it less readily permeable by water.

But there is another effect of natural manures upon the soil, and one about which very little is known. This is the influence of the manure upon the temperature of the soil. That such an influence is actually exerted is shown by Georgeson's experiments at Tokio, Japan. The soil, in this case, is light and porous, and consists of a volcanic ash mixed with 7 or 8 per cent. of humus. For the purposes of the experiment four equal-sized frames, each one foot deep, and without top or bottom, were sunk in the ground so as to bring the rim level with the surface. These were filled with soil, which was then thoroughly mixed with manure, this latter having previously been rendered as uniform in character as possible. Different quantities per acre were applied to each plot, and in a fifth frame no manure was added to the soil. The manure was partly decayed, but still rather long. A Fahrenheit thermometer was plunged to the depth of five inches in each box, and was read during each period of five days in the twenty-five days from October 27th to November 22nd, the observations being conducted as in the open field. The results, as tabulated in "Agricultural Science," are given in Table XXV., on the next page.

These gradations exhibit a sufficient regularity to suggest the conclusion that, provided all other conditions were similar, the quantity of heat developed in the soil, in consequence of oxidation, would be in direct proportion to the amount of manure applied. It is seen that the manured soil loses heat more rapidly than the unmanured. The fact that the averages for the last period in the case of the soils receiving twenty and ten tons of manure respectively are below the average of the unmanured soil is due to the circumstance that, as the manure is converted into humus, the capacity of the soil for holding moisture

is increased, and this, followed by an increase of evaporation, causes the soil to be cooler than a drier one, because evaporation involves the abstraction of heat.

According to the observations of Professor Penhallow, it appears that during the summer months the soil, at a depth of three inches, maintains a temperature which is constantly higher than that of the immediately overlying layers. Radiation and, more especially, evaporation affect these superficial layers, whilst the mechanical condition

TABLE XXV.—SOIL MANURED AT THE RATE PER ACRE OF

	None.	80 tons.	40 tons.	20 tons.	10 tons.
	deg.	deg.	deg.	deg.	deg.
Average of first five days	60·5	65·1	63·1	63·8	62·5
Excess over unmanured soil . . .	—	4·6	2·6	3·3	2·0
Average of second five days	58·5	62·2	61·3	60·2	59·5
Excess over unmanured soil . . .	—	3·7	2·8	1·7	1·0
Average of third five days	57·2	60·4	59·3	58·4	57·8
Excess over unmanured soil . . .	—	3	2·1	1·2	0·6
Average of fourth five days	54·7	56·8	56·2	55·3	54·8
Excess over unmanured soil . . .	—	2·1	1·5	0·6	0·1
Average of fifth five days.	50·8	52·5	51·6	50·1	48·9
Excess over unmanured soil . . .	—	1·7	0·8	—0·7	—1·0

of the soil also exerts an influence. A loose, porous soil evaporates its moisture much more rapidly than a compact one, hence its temperature must be lower. Actual observations indicated a difference of temperature between compact and porous soils varying from 0·1 deg. C. in the morning to 6·2 deg. C. in the afternoon—a difference of great importance where the growth of plants is concerned. Prof. Penhallow concludes that a proper knowledge of the temperature of the soil will indicate the time for planting particular seeds, and the depth at which they should be

planted as determined by the condition and character of the soil. When the cultivator gently packs the earth over his newly-planted seed, he derives a measure of benefit in the higher temperature of the soil at that spot where germination is accelerated. Similarly, it is clear that cultivation during periods of excessive heat must tend to avert some of the evil results otherwise following from an excess of temperature.

Reference was made on page 83 to the increased water-holding power of a soil as the dung applied to it became more completely converted into humus; and on this point there is much instruction in Table XXVI., from "How Crops Feed." Coarse quartz sand, which is capable of holding 25 per cent. of water by weight, has been found when finely pulverized to hold 53·3 per cent. Clay, according to its quality, holds from 40 to 70 per cent. of water; brick clay about 66 per cent.

TABLE XXVI.—WATER-HOLDING POWER OF SOILS.

	Per cent.
Quartz sand	25
Clay soil (60 per cent. clay)	40
Loam	51
Ploughed land	52
Heavy clay (80 per cent. clay)	61
Pure grey clay	70
Fine carbonate of lime	85
Garden mould	89
Humus	181
Fine carbonate of magnesia	256

As is indicated in this table, humus has a marked influence upon the water-holding capacity of a soil. The surface soil of the wheatfield at Rothamsted, sampled in the month of January when saturated with water, yielded only 33 parts of water per 100 of dry soil on the unmanured land, but 66 parts of water per 100 on the land which had received farmyard manure annually for 26 years.

THE ORIGIN OF SOILS.

As regards their immediate origin, soils are either formed by the disintegration or weathering of the underlying rock, in which case they are distinguished as sedentary, indigenous, or local; or they are brought from a distance, as in the case of glacial detritus, or of the alluvium deposited by a river near its mouth, and are then called erratic, exotic, or transported soils.

The origin of local soils may be well illustrated by the mode of formation of the soil on the impure oolitic limestone of the Cotteswold Hills. Figure 5, page 107, represents the face of a quarry; the soil at the top is merely a superficial bed, between it and the virgin rock are two beds more or less distinct, which manifestly represent different stages in the transformation of the hard solid rock into loose soil. The upper of these two, generally termed the subsoil, differs from the overlying soil in containing more carbonate of lime, in being greatly deficient in humus, and abounding in stones the size of which increases with the depth. The other consists exclusively of these stones (brash), which, becoming progressively larger and larger, pass gradually into the continuous rocks below. To account for these appearances, it is only necessary to bear in mind the solvent power of water containing carbonic acid, and to remember that the deeper such water percolates downwards, the more saturated with dissolved salts will it become, and therefore the less capable of

effecting further solution of rock-substance. The surface soil will contain the insoluble silica and alumina which were present in the impure limestone, some undissolved carbonate of lime, and humus. The local soils overlying the Chalk of the southern counties of England have a similar origin; and so completely has the carbonate of lime been dissolved away from the covering of soil that it is often necessary to top-dress it with chalk-rock. In that part of Britain which lies in the main north of a line which may be drawn from the mouth of the Severn to that of the Thames, the soils are more generally of the transported rather than of the local character, and there may consequently be little or no relationship between the rock below and the soil above. For this reason the Chalk area of Norfolk, for example, supports a very different soil from that which rests upon the Chalk area of Wiltshire; in the latter case the soil is the offspring of the underlying chalk rock, in the former case it is not. The soil on the Cheviot Hills, however, is local.

Very low forms of vegetable life, such as lichens, and then mosses, first appear on a young soil, and these disturb its chemical composition; thus, lichens which grow on limestone yield on analysis oxalate of lime. The decay of such low plants gradually confers on the soil a small amount of humus, and so it is slowly prepared for the growth and nutrition of other plants higher in the scale.

As bearing upon this subject, Sir John Lawes says, that if we were to take various rocks—granite, slate, limestone, etc.—and, after grinding them to different degrees of fineness, were to mix them together in different proportions, we could, from the known composition of these rocks, produce soils which would contain the most important mineral constituents of plant-food in

very different proportions. "Assuming that we purposely made one soil as rich as we could in this food, one as poor as we could, with two others in intermediate stages, and we then left them exposed to the ordinary influence of sun and rain,—I am here assuming the experiment to be tried upon several acres, and the artificial soil to be several feet deep,—we should find that the seeds of plants carried by the winds and other agencies would spread and grow upon these soils with very different degrees of rapidity; and, assuming that we were able to watch the process for thousands of years, we might see several remarkable changes in the character of the vegetation." The character and amount of the vegetation would, in fact, differ greatly on the various soils, and the largest amount would be found on the soil where the plants could get the largest quantity of food.

As, however, plants cannot grow without nitrogen, and as the rocks which have been mentioned contain no nitrogen, how could vegetation flourish on these nitrogen-free soils? How, indeed, upon any new soil occurring naturally can plant growth make a start? "There being no carbon or combined nitrogen in the soil, the first plants would be entirely dependent upon what they could obtain of these substances, directly or indirectly, from the atmosphere. Rain water always contains ammonia, and the plant and the soil may condense a certain further amount from the atmosphere; but growth, even in the soil richest in mineral food, would at first be small, as the decomposition of carbonic acid and fixation of carbon would be limited by the amount of combined nitrogen which the plant could obtain from the sources mentioned above, and it would be much greater where the most abundant mineral food existed, as every particle of the

available nitrogen would be there used up; while, where there was less mineral food, some of the combined nitrogen might pass through the soil and be lost.

"Each year a certain portion of the vegetable growth dies off; leaves and branches fall, and portions of the roots decay. Part of the organic portion which falls upon the surface of the ground returns again to the atmosphere, but a certain part remains, and, added to that which decays underground, becomes available for future growth. The atmosphere of the soil, which at first differed little from that which exists above it, becomes highly charged with carbonic acid, which decomposes the minerals in the soil; and thus, year by year, more and more of the nitrogen collected by each generation of plants becomes available for the generation that succeeds it."

The carbonaceous matter which thus accumulates is known by the general term of Humus, under which may be included "all those organic compounds in the soil which have gone through certain stages of decay since they formed parts of living vegetation. These compounds may be distinguished from living vegetation by their containing a larger proportion of nitrogen to the carbon."

There is a great deal yet to be learnt about the organic matter which naturally exists in the soil. The name of Humus is familiar enough; but to a very considerable extent it still remains little more than a name.

The mould of cultivated fields is made up of inorganic and organic ingredients, the former being derived from the weathering of rocks, and the latter tracing their origin to plants or animals. The percentage of organic matter in a soil, or, in other words, the quantity of humus, is in a great degree the measure of its fertility. It is true that this humus cannot directly serve as plant

nourishment, though early investigators thought it could; nevertheless, the products of its decomposition are highly important as sources of plant-food. Nor, in connection with the cultivation of the soil, should the physical properties of humus be overlooked. The formation or production of humus is most intimately connected with the plant and animal life of the soil, and with the reaction of the one upon the other. After the crumbling of the rocks or stones, in consequence of the action of various weathering agents, such as water, air, and changes of temperature, various low forms of plant life, firstly lichens, and afterwards mosses and ferns, settle upon the mineral fragments, and, as they decay, become incorporated with the earth which supported them. To this plant-refuse are added the products of the decomposition of animal organisms. These processes are continuously repeated, and are, therefore, always in progress, and in this way there gradually accumulates a rich layer of humus.

The products of decomposition which thus arise constitute the source of the humus of the soil; but its character will vary according to the accompanying conditions of moisture and temperature. As the decay progresses, the nature of the humus changes, and eventually it becomes reduced chiefly to water, carbonic acid gas, and ammonia, substances which are capable of directly administering to the food requirements of vegetation; and thus the same elements may again enter upon the cycle of which life and death are but alternating phases.

The decay of the organic matter involves its oxidation, or slow combustion, for which it is indispensable that there should be a free penetration of the air, and this is much facilitated by a regular working of the soil. Furthermore, certain micro-organisms play a significant

part in the decomposition of the organic matter. It may, indeed, happen that the decomposition proceeds to such an extent that the nitrogen is even set free, and thus becomes lost to vegetation. The small organisms are likewise highly important on account of their capacity for converting the organic matter into a form assimilable by plants. With these minute forms of life are associated other organisms, such as the earthworm, which has been demonstrated by Darwin to play a most significant *rôle* in the production of vegetable mould. It is no uncommon occurrence, especially in autumn, to see the small heaps of fine earth, or "castings," which worms eject at the mouths of their burrows. These castings have passed through the intestinal canal of the earthworm, and are, therefore, rich in speedily available organic matter, so that the surface layers of the soil become fertilized by the drying and crumbling of the castings. Through the burrows which the earthworm makes in the soil the entrance of atmospheric air is facilitated, and the decomposition of organic matter becomes thereby accelerated. Water also finds a free and open passage along these burrows, and, in virtue of its solvent properties, it is able the sooner to convert the mineral ingredients of the soil into soluble plant food. Earthworms are further of service in bringing the organic residues and mineral ingredients of the soil into closer intimacy, thoroughly mingling them together, and thereby adding to the sources of fertility within the soil. When it is remembered that, according to Victor Hensen, there exist upwards of 50,000 earthworms in an acre of agricultural land, it must be at once evident how important is the work of this humble annelid in connection both with the formation of humus and with the tilling of the soil.

As regards the physical properties of humus, it is a well-established fact that the temperature of the soil is one of the chief factors in the favourable development of plant life. The high specific heat of humus, that is, the comparatively large quantity of heat required to raise the temperature of a given weight of humus one degree, affords the reason of the difficulty with which the temperature of a soil rich in humus is appreciably increased; on the other hand, the cooling of such a soil is an equally slow process. The colour of the soil also exercises an influence upon its behaviour with regard to temperature; and it is a familiar fact that the more the humus accumulates in a soil the darker the latter becomes. The capacity which the soil has for retaining water is intimately related to its richness in humus.

It would be unwarrantable to conclude that the more humus a soil contains the more fertile that soil becomes, for it is possible for a soil to be overladen with humus. Indeed, by the excessive application of farmyard manure, or by the undue accumulation of crop residues within the soil, it may become disadvantageous to cultivate it. In peaty soils or moorlands this condition may often be seen.

The quantity of humus in cultivated soils is very variable, ranging from 2 to 9 per cent. Sandy soils need to be enriched with humus, not only on account of its containing fertilizing ingredients, but equally for its moisture-holding capacity. In contrast with the free, open, sandy soils are the firm, dense, water-holding clay soils; in these, humus has a physical value on account of its property of loosening, and thereby opening and aërating the soil. Consequently the very growth of crops may improve the soil for future crops, because the crop-residue, in the form of roots and stubble (see page

57), goes to increase the store of humus which the soil contains. Hence, in some cases to increase, and in others to judiciously regulate, the quantity of humus contained in the soil, is certainly not one of the least important objects to which the cultivator can direct his operations. By the process of green manuring—that is, raising a crop of mustard or any other quick-growing plant, and ploughing it in green—the amount of organic matter in a soil may be readily increased.

In writing on this subject in the *Journal of the Royal Agricultural Society* (1890, page 83), Sir John Lawes says:—

"Humus (in which term I include all vegetable matter in a certain state of decay) is very insoluble in water; but sooner or later it assumes the form of nitric acid, which combines with lime or other alkaline substances in the soil, and then becomes very soluble in water. These compounds rise and fall with the water in the soil, coming to the surface in dry weather, and passing into the drains, in the absence of growing vegetation, in wet weather. When a crop is in the full vigour of growth, the soil-water may contain no nitrates, the crop having taken them all up; but at all other times the soil-water contains more or less nitrates. Being soluble in water, and entering into no combination with the soil, nitrates cannot accumulate. Each year fresh nitrates are formed from the decomposition of the humus, the fertility of land depending largely upon the amount of nitric acid liberated every year. What we call 'condition,' is so much added to the stock of organic matter, which in the course of a few years is decomposed, yielding nitric acid and mineral substances."

As further illustrative of what is understood by "condition," the same author elsewhere remarks :—

"It is very desirable to distinguish between the natural fertility inherent in soils, which is given in exchange for rent, and the additional fertility which the tenant brings upon the land at his option, but cannot altogether remove."

The principle is sometimes tersely enunciated thus:—Fertility is the property of the landlord, "condition" is the property of the tenant.

Our inadequate knowledge of humus is not much advanced by stating that this substance may roughly be regarded as consisting of humin and humates. By treating soil with cold dilute hydrochloric acid, and washing it, the bases which were combined with humic acid in the form of humates are removed. By the further addition of ammonia, soluble ammonium-humates are produced, and insoluble humin remains. The alkali humates—those of potash, soda, and ammonia—are soluble, but the humates of lime and of iron, which are the combinations in the soil, are not soluble. All humates are colloid bodies (see page 46). Clay and humates are the principal cementing materials in soils.

By the agency of bacteria in the soil, the nitrogen of humus is converted into ammonia and nitric acid, whilst its carbon is simultaneously oxidised to carbonic acid. Two species of bacteria are concerned in the final stages of the nitrification of ammonia or of amides, the one producing nitrites, and the other effecting the further change into nitrates. The salt of nitric acid usually produced is nitrate of calcium, the base of which is furnished by the carbonate of lime present in the soil.

TILTH.

Most of us remember the story of our childhood, relating how an old man in his dying moments called his sons around him, and told them that in the garden a treasure was hidden which, if they would dig diligently, they would find. And dig, we are told, they did, as seldom had garden been dug before; yet of treasure of silver or treasure of gold found they none, so that their disappointment was great. But in the fulness of time the earth yielded up her increase; and when it was seen how wondrously bountiful was the harvest from this much-worked garden, the father's meaning dawned upon the minds of his sons, and they knew then that the old man's last words were words of wisdom. He lived so long ago that history has failed to bring down his name, otherwise it would deserve equal honour with that of Thomas Tusser, who, amongst many other quaint verses, penned, three centuries ago, the easily-remembered couplet:—

> "Good tilth brings seeds,
> Ill tilture, weeds."

A good tilth is the indispensable antecedent to a favourable seed-bed, and how important is the seed-bed is evidenced plainly enough by the trouble that is taken to secure it, and by the varied kinds of implements which are devoted to the working of the soil. The terms, almost of endearment, which the tillers of the soil apply to it, show how large a place it occupies in their thoughts; and when we are told of a soil that it is open, free-working,

mellow, or in good heart, our opinion of it increases accordingly. Not that all soils are such, for, unhappily, there exist those which are known as hungry, stubborn, stiff, cold, or unkind. But most soils are capable of amelioration, in that it is possible to improve their tilth.

It will have been gathered from the earlier chapters that in the production of tilth the silent operations of Nature commonly play a prominent part. In winter this is particularly noticeable, and one of the compensations of a hard winter is the finer state of sub-division in which surface soils emerge from it. Charged with water which, at the moment of freezing, undergoes in all the pores of the soil a minute yet sensible expansion, the particles of the soil are sundered from each other, and gradually fall down into a fine powder. The severity of the weather in some winters is particularly serviceable in this respect, and affords a good example of what geologists term epigene, or surface action. A practical illustration is seen in the manner in which large solid lumps of chalk, scattered as top-dressing over the land in Chalk districts, crumble down during the winter into a fine powder. Farmers who top-dress with chalk or marl will, of course, be very familiar with this phenomenon, which, though in the main physical, is partly chemical.

That a good tilth provides a favourable bed for the seed, that it is conservative of the moisture which the seed requires, that it facilitates the exploration of the soil by the delicate rootlets and root-hairs whose duty it is to absorb the nutrient solutions on which the plant is dependent, are points well known and generally understood. But there are other aspects in which tilth may be viewed, chief among which is the relation between tilth and underground moisture.

Consider for a moment two extreme cases. In each let there be a soil well stocked with all the elements of fertility, so that, chemically, it is a thoroughly efficient soil. But, in the one case, let this soil be completely dry, that is, quite devoid of moisture, and for all cultural purposes it will be as barren as the sands of the Sahara. In the other case, let it be water-logged; then with this surcharge of moisture it becomes a sour marsh. It follows, therefore, that fertility is not exclusively determined by chemical conditions, but by these taken in conjunction with physical properties. Of the latter the most important is capillarity; and although some reference has already (page 78) been made to this subject, it will repay further study.

No physical property is more familiar than that of capillarity, or capillary attraction. When a piece of sugar is held with one corner dipping in a cup of coffee, the brown liquid quickly suffuses the whole lump. When a fresh wick is allowed to depend into the oil-reservoir of a lamp, the fluid speedily travels up the fabric. When a sheet of blotting-paper comes in contact with a drop of ink, the latter rushes into it with a celerity that would astonish us were we not familiar with the sight from our copy-book days onward. These are instances of capillarity, and the phenomenon is dependent upon the presence of innumerable very fine tubes (Latin, *capillus*, a hair). As the internal diameter of these narrow tubes increases, so does the power of capillary attraction diminish. Myriads of such tubes exist in the soil; and the finer the soil the more delicate, and consequently the more efficient, do these tubes become. On the other hand, the coarser a soil is, and the more inferior the tilth, the more do the delicate narrow tubes give place to others of wider bore.

However dry and parched a cultivated soil may happen

to be, it is not necessary to dig very deeply before moist soil is reached. By digging to a much greater depth the water table, or line of water level in that spot, will be found; and it will be seen that from the water-level upwards the earth is moist, though the actual soil has lost all, or nearly all, its moisture. Why should it not be moist up to the surface? Is it because the surface is so largely exposed to evaporation? Partly so, no doubt; but it is a question not so much of evaporation as of capillarity, that is, of tilth. The capillary tubes, having lost most of their moisture by evaporation, have crumbled to form other more open tubes, too broad for the water to travel along, and hence the surface soil has been deprived of those myriads of minute invisible conduits which would have enabled it to continuously draw its supplies of moisture from the reservoir below. Had the surface soil been kept in a state of fine tilth,—and this can be done by stirring it sufficiently frequently,—the moisture would have travelled up from below to replace that which evaporated.

When rain falls upon the soil, some of it sinks down to replenish the stores below; but during the season of active growth, and particularly in a droughty season, there is a movement of moisture from below upwards. This moisture replaces that lost at the surface by evaporation; and its direction is such that it tends to keep the soluble plant food where it is wanted, that is, about the roots of the plants. If enough water be poured into a saucer in which stands a flower-pot full of earth, the surface of this mould will at length become moist, and the water will necessarily have travelled upwards by capillarity. But here another important point comes in. If all the capillary tubes are open to the surface, evaporation can proceed from them so freely that the underground store of moisture may be

insufficient to supply the continuous demand. Hence, again, it is desirable to keep the surface soil, by frequent stirring, in such a state that the capillary tubes are broken or interrupted a little below the surface. In this case the mere superficial covering of mould acts as a soil mulch; and, like a layer of leaves, or grass, or farmyard manure, it protects the moisture beneath, as is well seen in the case of the experiment quoted on page 77. Hence, an occasional slight stirring of the superficial soil serves to conserve rather than to dissipate the underlying moisture.

It cannot be too frequently stated, that land under crop gives up more water than a bare fallow, other circumstances being the same. But when it is remembered that all soil foods enter the plant in solution, and that the excess of water which thus travels into the plant is evaporated at the leaves, the drain which growing crops must exert upon soil moisture becomes apparent. The rapidly growing sunflower is cultivated in large quantities in summer around dwellings in damp or marshy situations, because this crop keeps down excessive moisture in the soil; and it is often noticed how the wide-spreading roots of a large tree serve to keep the surrounding soil dry, especially during a period of summer drought. In this relation, weeds assume a very important aspect. That they are thieves of crop food is certain, but is this the worst that can be said of them? Do they not occasion far more mischief as dissipators of soil moisture? In all probability they do. They spring up in a very short time in summer, they grow rapidly, they soon cover the ground with a green mantle, and they suck the soil dry. Then it is that those crops which cannot be hoed begin to suffer; and very frequently it is thought that the manuring has been at fault, whereas a foul seed-bed is the origin of the mischief.

Viewed in this light, the importance is enhanced of a clean seed-bed in a state of good tilth.

It is a matter of observation, that when a plough-pan has formed, or a layer of farmyard manure has accumulated beneath the soil, the over-lying soil soon becomes dry, and speedily suffers from drought. The explanation, of course, is, that the surface soil has been cut off from capillary continuity with the moisture-laden earth below, and there has been no upward current of moisture to replace that which has been lost by evaporation at the surface.

THE CONSTITUTION OF SOILS.

It may in general terms be stated that, within certain limits, a soil is fertile in proportion to the varied character of its ingredients. A soil composed entirely of one proximate constituent lacks the essential elements of fertility, hence it is that a pure clay, or a pure limestone, or a pure sand, is incapable of growing crops; whereas a soil consisting of a suitable mixture of these ingredients is likely to be very fertile. Tusser wrote :—

"All gravel and sand
Is not the best land;
A rotteny mould
Is land worth gould."

Indeed, experience proves that a soil is best adapted for purposes of cultivation when it contains of—

Sand (siliceous and calcareous) .	from 50 to 70 per cent.
Clay	" 20 " 30 " "
Pulverized Limestone . . .	" 5 " 10 " "
Humus	" 5 " 10 " "

It thus contains enough sand to make it warm, and pervious to air and moisture; enough clay to render it moist, tenacious, and conservative of manures; enough limestone to furnish calcareous material and to decompose organic matter; and, lastly, sufficient humus to assist in supplying the alimentary needs of the plant, and to aid in maintaining the carbonic acid in the interstitial air of the soil. The

reason that alluvial soils are generally so fertile is the mixed mineral character they possess, owing to their having been usually derived from the disintegration of various kinds of rocks, and not from one kind only. Such a soil as that indicated in the above table is, however, the exception rather than the rule in nature, most soils being characterized by too great an excess of one or more of the ingredients.

Thus, many soils consist chiefly of sand and clay; and they have been classified according to the proportions of these substances present. When, in a soil of sand and clay, the latter forms not more than 10 per cent. of the weight, a *sandy soil* results; with 10 to 40 per cent. of clay, a *sandy loam;* with 40 to 70 per cent. of clay, a *loamy soil;* 70 to 85, a *clay loam;* 85 to 95, a *strong clay.* With a still higher percentage of clay the soil approaches a pure agricultural clay. A mixture of clay and pulverized limestone—that is, a calcareous clay—constitutes a *marl* when the limestone is from 5 to 20 per cent. of the total weight; should the limestone exceed 20 per cent., a *calcareous soil* is the result. A mixture of sand and pulverized limestone produces a soil which may be termed, for want of any other word, a *calcarene* (Latin, *calx*, lime, and *arena*, sand).

The reason that a mixing of two different soils usually effects an improvement is, that each is in a position to supply some of the deficiencies of the other. Not uncommonly, this admixture takes place naturally, as where two rock formations of different mineral character crop out at the surface of the earth, side by side; the soil along the common outcrop will be more fertile than the purer soil on either formation by itself. Numerous examples exist which corroborate this general rule, and, anticipating

what will subsequently be said, it may be instructive to cite a few of them at this stage.

On the Mendip Hills, in Somerset, the soil is derived from the Carboniferous Limestone, and this formation on the lower slopes adjoins the Lower Limestone Shale; the soil occurring along the common outcrop of the two formations is more fertile than that on either alone. In Northamptonshire, the Oolite, consisting chiefly of limestone, and the Lias, consisting in the main of clays and marls, crop out in very complicated ramifications, so much so that the superincumbent soil is of a sufficiently varied mineral character to give rise to the rich and fertile districts around Rockingham and Kettering. Occupying the central region of the Weald of Kent and Sussex is the Hastings Sand, surrounding which is the Weald Clay; the soil resulting from the weathering down together of the sands and clays along their common line of outcrop is better than that supported exclusively by either. The Chalk formation, overlaid naturally by poor light soils, affords an admirable example of natural amelioration along both edges of its outcrop. The marly base of the Chalk rests upon the Upper Greensand, and their common outcrop is covered by a soil which, containing as it does clay, sand, and limestone, is very fertile. The Farnham hop-lands afford a good example of this case; and similarly constituted examples occur in West Wilts and in the counties of Oxford, Bedford, and Cambridge The Chalk in turn is overlaid by the Woolwich and Reading beds (formerly called the Plastic Clay, and still commonly referred to as such in agricultural works); in this case the common line of outcrop is marked by a mixing of limestone (chalk) on the one hand with clay and sand on the other; and the result again is a much better soil than

either the Chalk or the Woolwich and Reading formation supports separately; the free-working barley soils of part of Essex, and of other counties adjoining the Thames basin, occur along this fortunate outcrop.

There are other cases of natural mixing not dependent upon a common outcrop. Thus, on the north side of the fertile valley of the Tees, calcareous particles of the Magnesian Limestone have been washed into the soil, resting upon the New Red Sandstone, and it is consequently generally good; but beyond the reach of the ancient floods the soil is a heavy clay, expensive to cultivate.

Since nature produces such satisfactory results by the intermingling of different kinds of soils, the example is one which is not lost upon the cultivator of the soil. Hence, indeed, arose the many familiar and well-approved agricultural operations known as chalking, liming, marling, claying, warping, and even paring and burning, all having for their object the amelioration of the soil, and all capable of being regarded as an effort to bring about artificially what, in the case of alluvial soils, and of those resting upon the common outcrop of differently-constituted formations, is effected naturally.

The Trias, or New Red formation, which occupies so much of the area of the English Midlands, affords some typical examples of artificial improvement of soils. Where, on this formation, a red sand rests upon an underlying red marl, the latter is brought to the surface and incorporated with the sand to form a rich friable loam of great fertility. The number of old marl pits in Cheshire bears witness to the extent to which the incorporation of transported marl with sandy soils has been followed in that district. The value of the Fen land is, or was, maintained by the occasional digging up of the Oxford Clay (there known as the

Fen Clay) beneath it, and incorporating this with the surface soil. £4 an acre has been paid for this work.

Where the Drift deposits, consisting mostly of clay and partly of sand, left by the ice that spread over Britain during the last Glacial Period, thin out, or die away upon the surface, the commingling of drift soil with that of the underlying rock is inevitable, and the result is nearly always satisfactory. Numerous cases occur upon the Chalk in Norfolk and Suffolk, and upon the Oolite in Lincolnshire and Yorkshire. In the central valley of Scotland, watered by the Forth and Clyde, and extending from the metamorphic rocks of the Highlands on the north down to the uprising Silurian Lowlands on the south, the commingling of Old Red sandstones and marls, Carboniferous shales and limestones, fragments of igneous rocks and glacial detritus, has resulted in the formation of an arable soil which, under judicious cultivation, has attained a remarkable degree of fertility.

The foregoing examples, which might be multiplied indefinitely, all converge upon the teaching of one great lesson, which is, that the incorporation with any soil of mineral matter differing from it in composition and in texture will generally result in bringing it nearer to the character of the ideal loam.

The formation of soils, both local and transported, is still in progress; it always will be, so long as dry land exists, and the epigene or surface action of meteorological agents continues. The transported soils still in process of formation are chiefly either accumulations of rain-wash, or brick-earth, on the lower valley slopes; or alluvium spread out on the banks, or near the mouths, of rivers. The fertility of alluvial soils is proverbial, and it arises from a combination of both physical and chemical proper-

ties. The fine state of mechanical subdivision on the one hand, and the varied mineral character of the rocks whence the detritus is derived on the other, contribute to this end. The Severn, which rises among the Lower Silurian rocks, and derives its waters from that and nearly all the intervening strata up to the Lias, deposits in its lower reaches an alluvium of an extremely mixed mineral character well displayed in the fertile vale of Berkeley. Within certain limits, it may be taken almost as a geological axiom, that the fertility of a soil will be greater the more varied is its lithological character.

The influence of the underlying solid formation on the superjacent soil must obviously be controlled to some extent by the circumstance as to whether the soil is a local or a transported one. In the case of deep accumulations of Boulder Clay, the effect of the underlying rock is reduced to a minimum, and Boulder Clay soils, resting on very different formations, may be closely similar in their properties and capabilities,—variations in contour, aspect, and geographical position, rather than in the solid geology beneath, being then the dominating factors. But that the character of the underlying solid rock is capable of asserting itself is evidenced in, for example, the case of the Old and New Red Sandstones and Marls, the partiality of orchard fruit-trees for which is as characteristic a feature in Scotland, where the Old Red in the Carse of Gowrie is masked by Boulder Clay or Till, as it is in Herefordshire, Gloucestershire, and Devonshire, where the soils are of more local origin. Below the southern limits of the Glacial Drift, local soils are the rule rather than the exception. They originate from the decay of the solid rocks, and, in the Oolites of the Cotteswolds, it is sometimes possible to see sections (see fig. 5) in which the gradations from

the solid rock below into the loose friable, though often brashy, soil above may be distinctly traced. In the case of the Carboniferous Limestone, and of the limestones of the Lias, Oolite, and Cretaceous series, in the south of England, it is, however, the residue from the chemical, rather than that from the mechanical, agents of disintegration, which goes to form the soil. The solvent action of rain-water containing carbonic acid in solution results in

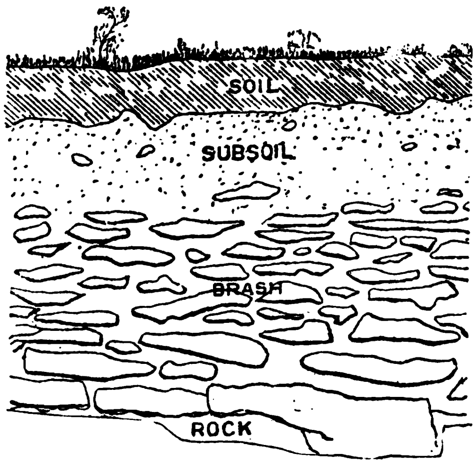

FIG. 5.
DIAGRAM SHOWING THE MODE OF FORMATION OF A LOCAL SOIL.

the removal, in the drainage waters, of the carbonate of lime of which these calcareous rocks mainly consist, the aluminous or earthly residue constituting a soil which is almost free from carbonate of lime. The analysis of the soil of an arable field on the Chalk slopes in South Hants, in a locality where the whitish chalk-rock is within half a foot of the surface, gave only 15 per cent. of carbonate ot

lime; and yet to plough more than about four inches deep would result in bringing up enough chalk from the subsoil to injure the soil to such an extent that it would require the lapse of a number of years to restore it to its former condition. On the lower levels of the slopes of the Chalk Downs, where the soil formed *in situ* receives additions from that which rolls down the slopes, but yet, where all the soil is the offspring of the chalk-rock, the application of chalk to the land is a familiar part of farm practice. Where the limestone soils are under grass, the covering of herbage protects the land from further mechanical degradation, and checks the denudation of the surface caused by the removal of rain-wash, but it cannot check solution; indeed, the presence of decaying vegetable matter enriches the interstitial air of the soils in carbonic acid, so that the rain-water, becoming more highly charged thereby, acquires additional solvent power. The humic acid of all vegetable soils is likewise a solvent which must not be overlooked, though not much is known on this point. The chemistry of the carbon of the soil is, indeed, an almost unexplored field of investigation; still, it is important to remember that the carbon of the soil is the source of much of the carbonic acid of soil-water. As a mechanical agent—that is, mechanical as regards the effect produced—in the disintegration of soils, the earth-worm is equally active both on arable and on pasture land, but in view of the work the plough does on arable land, it is, perhaps, entitled to a place little inferior to that of the earthworm as a geological agent.

THE SOILS OF THE BRITISH ISLES.

IGNEOUS ROCKS.—Granite soils owe what fertility they may possess to the decomposable nature of the felspar, and (if present) of the hornblende; the iron and magnesia of the latter contributing especially to make the soil productive, though even these will not avail much if, as is often the case, the soil is at any considerable elevation above the sea-level. In Cornwall and Devon the weathered blocks of granite have been removed from the surface and employed in making walls, and the enclosed fields have been brought into a fair degree of productiveness. Granite occurs in many isolated tracts in mountainous regions.

Besides Dartmoor in Devonshire (fig. 6, p. 110), and various parts of Cornwall, granite is exposed in the Lake district of England; in Anglesey, Carnarvon, Merioneth, Cardigan, and other parts of Wales; in the Isle of Man; and in the western Lowlands, in the Grampians, in Sutherlandshire, and other localities in Scotland. In Ireland, granite is seen in various localities bordering the coast, but does not appear at the surface over the general inland area. The Mourne and Carlingford Mountains, Slieve Croob, the Ox Mountains, and the Western Highlands, together with parts of the counties of Donegal, Galway, and of Dublin, Wicklow, and Wexford are some of the best-known localities.

The term trap rocks is indifferently applied both to

ancient volcanic rocks and to those igneous rocks, whether old or new, which were forced into fissures of overlying

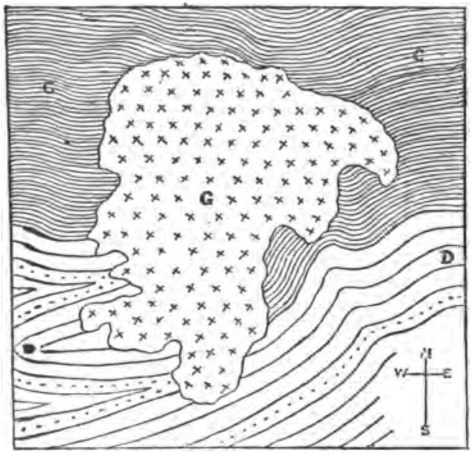

Fig. 6. Exposure of Granite on Dartmoor.
G, Granite. D, Devonian rocks. C, Carboniferous rocks.

rocks without reaching the surface (fig. 7). Where these latter are now visible they owe their exposure to the cir-

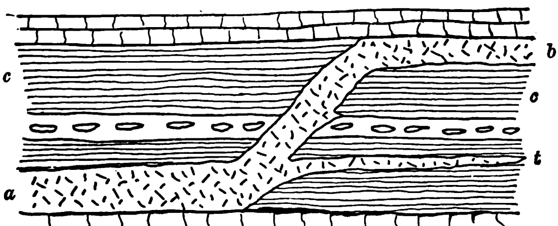

Fig. 7. Sheet of Igneous Rock,
a b, traversing shales, *c c*, and sending off a tongue, *t*.

cumstance that the superincumbent rocks have been weathered away. The traps, being usually harder than

the surrounding rocks, often stand out in prominent tabular masses, thus forming a succession of terraces or steps on hill slopes. Hence the word trap, from *trappa*, Swedish for a flight of steps. Trap-rocks, on account of their more varied mineral composition, are more easily crumbled and yield more fertile soils than granitic rocks; their decay produces soils consisting of clay, and containing potash, lime, magnesia, and iron (see Table VIII., p. 26.) Decomposing trap is used as a mineral fertilizer on other soils. Trap-rocks occur in a few localities in Wales, in various parts of Central and Western Scotland, and in the south-east of Ireland in the counties of Wicklow, Waterford, and Wexford, in addition to the Miocene basalt of Co. Antrim in the north (fig. 8).

Palæozoic Series.—The Pre-Cambrian or Laurentian rocks are of little or no agricultural importance in the British Isles. The only localities where they occur to any extent are the extreme north-west of Scotland and the islands of the outer Hebrides.

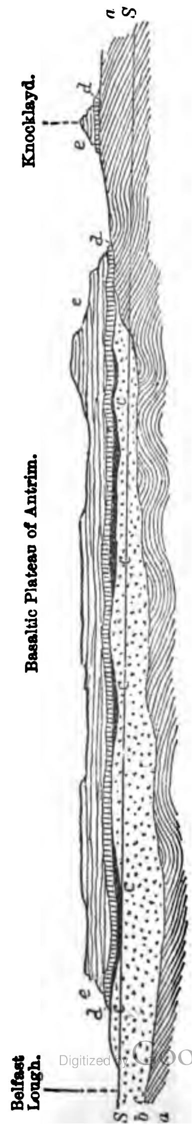

Fig. 8. Diagrammatic Section across the Plateau of Antrim: Distance about 40 Miles.
e, Tertiary Basalt. *d*, Cretaceous. *c*, Lias and Rhætic. *b*, Triassic marls and sandstones. *a*, Palæozoic rocks. *SS*, Sea level.

The southern part of the north-west coast of Scotland, certain Welsh localities, the Charnwood Forest district in Leicestershire, and two areas on the south-east coast of Ireland are Cambrian. The Irish localities are the Hill of Howth; from Bray Head to the town of Wicklow; and from Cahore Point southward along the coast of Co. Wexford. As the Cambrian consists chiefly of hard slaty rocks, it yields either poor thin soils, or cold clays difficult to work and only amenable to high-farming.

Silurian.—Nearly the whole of the Scotch Highlands, a great part of the Lowlands, most of Wales, Cumberland, and large areas on the east, west, and north coasts of Ireland are occupied by Silurian strata, which are frequently highly contorted and metamorphosed. Hard grits and slates are prevalent, and these being difficult of decomposition, little soil is formed, especially on the more elevated lands, which are therefore entirely devoted to pasture. At the feet of hills, however, and on slopes where glacial detritus has been mixed up with the decaying rocks, as in the Scotch Lowlands, the soil is fertile under good cultivation. In Wales the Upper Silurian forms cold muddy clays, difficult to work; but in Shropshire the Ludlow beds, around the town of that name, crumble down into a fertile soil. Arable soils derived from the Silurian are also seen in the counties of Carmarthen, Radnor, Shropshire, and West Herefordshire. Most of the remaining Welsh Silurians are under pasture. The accompanying section (fig. 9) illustrates the lie of the Silurian rocks between Ledbury and the Malvern Hills.

Old Red Sandstone and Devonian.—Under this head are grouped two very different kinds of rock, the Old Red Sandstone embracing rocks consisting chiefly of

reddish and greyish sandstones, and the Devonian comprising strata which more nearly approach the succeeding Carboniferous Limestone, being made up of slaty rocks, grits, sandstones, and limestones. In the British Isles the beds of the Devonian type occur only in Cornwall, South Devon, North Devon, and parts of Somerset.

Fig. 9.

Section from Ledbury to the Malvern Hills: Distance about 4 Miles.

j, Old Red Sandstone.
i, Ledbury Shales.
h, Aymestry Limestone.
g, Lower Ludlow Shales.
Wenlock Limestone.
e, Wenlock Shale.
d, Woolhope Limestone.
c, Upper Llandovery Beds.
x, *a*, } Schist and Gneiss.

The Old Red Sandstone in England and Wales extends from near Bridgenorth, in Shropshire, through a considerable area of Herefordshire, Monmouthshire, and Brecknockshire, into the counties of Glamorgan, Carmarthen, and Pembroke. It occupies numerous tracts in the Scotch Lowlands, on the southern flanks of the Grampians,

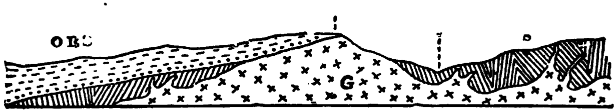

Fig. 10. Section near Thomastown, Kilkenny.

G, Granite. *S*, Silurian. *ORS*, Old Red Sandstone.

and on the north-east coast of Scotland, also in the south-west of Ireland, and at various outcrops in the central plain of that country (fig. 10). In no county is the Old Red Sandstone seen to better advantage as a soil than in Herefordshire; there the lower divisions of the Old Red

contain a great number of rounded pieces of impure limestone, called "cornstones," often embedded in marl, the whole decomposing into a soil of great fertility, its reddish colour being due to the presence of a considerable percentage of oxide of iron. As the cornstones do not allow water to pass through them without difficulty, it sometimes happens that when these form the subsoil the overlying soil is injured by the throwing up and retention of water. The Old Red yields one of the best natural pastures, and is the home of the far-famed breed of Herefordshire cattle; when cultivated, the soil gives fine crops of wheat and barley, and in some localities of hops, whilst its apple and pear trees have obtained for Herefordshire cider and perry a wide celebrity. The superiority of the Old Red soils over those of the adjacent older rocks is very apparent to the traveller journeying from Herefordshire westward into Wales.

The upper members of the Old Red Sandstone form a country the outline of which is usually hilly and undulating. The soil is pale red and stony, often only slightly productive, and is frequently left in moorland, which is sometimes wet and boggy. Examples may be seen upon the Mendip Hills of Somerset.

Carboniferous Limestone.—This formation, where it occurs in greatest purity, is a hard bluish limestone, and from the fact that it often rises into bold hills, as in the Peak of Derbyshire (fig. 11, p. 115), and lends itself to the formation of fine cliffs, scarps, and gorges, as in the Monmouthshire Wye and the Bristol Avon, it was formerly termed the Mountain Limestone. It usually occurs in Great Britain skirting the Millstone Grit that surrounds most of the coal-fields, and is seen in South Devon, parts of Somerset and Monmouthshire, and in Derbyshire, where it is

several thousand feet thick. When traced northwards into Northumberland and to the Vale of the Forth and Clyde, it is found to have greatly deteriorated in quality, being split up by intercalated beds of sedimentary material. The Carboniferous Limestone plays the same important part in Ireland as that taken by the Lower Silurian in the Scotch Highlands, for nearly the whole of the great Central Plain of Ireland is occupied by it. All this area was once covered by coal, which has been removed by denudation. Even now, however, the Carboniferous Limestone itself is not generally visible on the plain, as it is mostly covered up by beds of limestone gravel, by boulder-clay, by shallow lakes, or by extensive peat-mosses which occupy the positions of lakes that once existed. The Carboniferous Limestone is dry at the surface, and sends out springs at the base; its local soil is usually thin, and consists of a fine vegetable mould mixed with broken fragments of limestone. The natural herbage, amongst which the sheep's fescue-grass, Festuca ovina, L., is prominent, is very good, sheep showing a marked preference for it, and grazing it close to the ground. For this reason, and because of its great elevation in some districts, as in Derbyshire, it is mostly left in natural pasture. As it is favourable to the growth of timber, it is

Fig. 11. Diagrammatic Section across Derbyshire: Distance about 35 Miles.
a a, Carboniferous Limestone, flanked on either side of the anticline by Yoredale Beds, Millstone Grit, and Coal Measures.

frequently well wooded. It is largely cultivated in the Mendip Hills, where it yields good crops of oats, barley, clover, and roots, the situation being too high for the profitable growth of wheat. Lower down, however, where the limestone and the underlying shales crop out together, the mixed soil produces good crops of oats and wheat.

MILLSTONE GRIT.—This deposit fringes most of the coal-fields, as may be well seen on the map in the case of the South Wales coal-field. It occurs also in Devonshire, and in the district occupied by the Pennine Chain,[1] separating the coal-fields of Lancashire and Yorkshire; likewise in a few localities amongst the Scotch Coal-Measures. It occupies several large tracts around the Carboniferous Limestone of Ireland, notably in the south-west. The soil of the Millstone Grit is of a poor gravelly character, and where the subsoil is of clay the overlying gritty beds become swampy. This formation is usually covered by worthless heaths or moorlands, the appearance of which contrasts anything but pleasingly with that of the adjacent Carboniferous Limestone.

COAL MEASURES.—The shales, clays, and sandstones, that crop out as the partings between the beds of coal, form at the surface a wet yellowish clay, the natural produce of which is sedges and heaths with but little grass. Where, however, there is a large proportion of sand the soil

[1] This long, gently sloping table-land, forming moors and mosses, fells and forests of many names, rarely sinking so low as a thousand, and often exceeding two thousand feet above the sea, is sometimes spoken of as the Pennine Chain of England. The rivers that run down its eastern slope have cut deep winding valleys into the rocks below, and expose the beds so clearly and frequently that the miners have given names to their different groups by which they familiarly distinguish them. Airedale, Wharfedale, Wensleydale, Swaledale, Teesdale, Weardale, are some of the best-known of these valleys.—Jukes's *Manual of Geology*.

becomes fairly productive, and is better utilised as arable land than for pasture. The fine deep soil in which is cultivated the liquorice-root employed in the manufacture of "Pomfret Cakes," is largely made up of the *débris* of the Pontefract Sandstone, a member of this series. The soils of the Coal-Measures, as well as those of the underlying Millstone Grit, require, after draining and cultivating, the application of lime, which assists to bring the soil into sufficiently good condition to yield fair crops of wheat, oats, turnips, and clover. The chief coal-fields of England and Wales are those of South Wales, Bristol and Somerset (fig. 12), Forest of Dean (Gloucestershire), Shrews-

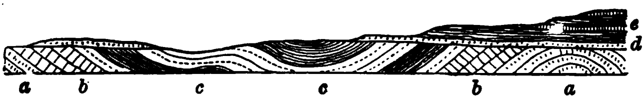

FIG. 12. SECTION ACROSS THE BRISTOL COAL-FIELD.
a, Devonian Rocks. *b*, Carboniferous Limestone. *c*, Coal Measures. *d*, Trias. *e*, Lias. *f*, Oolite.

bury, Coalbrookdale (Shropshire), Flintshire, Denbighshire, Anglesea, North Staffordshire, South Staffordshire, Warwickshire, Leicestershire, Derbyshire and Yorkshire, Lancashire, Cumberland, Durham and Northumberland. In Scotland are those of the Clyde Basin, Midlothian, Fifeshire, Clackmannan, Ayrshire, and Upper Lesmahago. The Irish coal-fields are those of Leitrim, Tyrone, Antrim, and Kilkenny. In the immediate vicinity of coal-pits, the conditions which exist are not favourable to vegetation, as will be evident to anybody who has passed through, for example, the "black country" around Wolverhampton.

The "Carbonaceous" rocks of Devonshire received the name of Culm-measures, because culm, which is a variety of anthracite, was obtained from them near Bideford, and

in other localities. They occupy a trough between the Devonian rocks of North Devon and West Somerset, and those of South Devon and Cornwall. The shales which occur amongst them are locally termed "Shillet," and the sandstones are called "Dunstone." The soil being mostly poor, the area is largely occupied by rough pasture, woodland, and moorland, diversified, however, by very charming river scenery.

ROTHLIEGENDE (German, red layers).—To this group belongs a series of marls and sandstones of Permian age, seen in the Vale of Eden, in a few localities in the south of Scotland, on the Cumberland coast, in Shropshire, and in the vicinity of the coal-fields of the English Midlands. Their soils are similar in most respects to those of the Trias which are described on page 123.

MAGNESIAN LIMESTONE.—This, also of Permian age, forms a narrow strip of land, on the east side of the Coal-measures, extending from Nottinghamshire up to the north side of the Tyne, there being a break in the continuity in Yorkshire. Magnesian differs from ordinary limestone in containing, besides carbonate of lime, a variable quantity, even as much as one-half, of carbonate of magnesia. Excess of magnesia in a soil renders it unsuited to plant-growth. The Magnesian Limestone soils are thin, light, dry, and easily crumbled, and are mostly under the plough, good crops of wheat and barley being the reward of high-farming. William Smith gave to it the name of Redland Limestone, which is now obsolete.

The Palæozoic strata, a description of the soils resting upon which has now been given, are practically confined to certain parts of the British Isles. Thus, both Ireland and Scotland are almost exclusively occupied by these old rocks, the most notable exception, perhaps, being that of

the fertile basaltic plateau of Co. Antrim in the former country, which dates back only to the Tertiary epoch. In England and Wales, again, the counties of Devon and Cornwall, the whole of Wales with Monmouth, Herefordshire, and Shropshire, and that major portion of the six northern counties which lies west and north of the Pennine Chain, are likewise entirely occupied by the outcrops of Palæozoic strata, with bosses of igneous rocks rising up here and there, just as they do in Scotland and Ireland. It is a noteworthy fact, that most of these Palæozoic areas are under permanent pasture; and this is due not only to the nature of the soil, but also to considerable elevation above the sea, as in the natural pastures of Wales, Cumberland, and Derbyshire, and likewise to the excessive humidity of climate to which the Irish, Welsh, and Cumbrian grazing lands are subjected. The nature of the soil and the prevalent moisture combine to make Ireland, for example, essentially a grazing, and therefore a stock-breeding, rather than an arable country. The statement made respecting the general character of the Palæozoic strata must, however, not be received in too wide a sense, as there are certain exceptions, notably in the case of the Old Red Sandstone, and of the red and yellowish sandstones and marls (Rothliegende) of Permian age, as witness the Old Red arable soils which attain their highest perfection in the fertile county of Herefordshire, and the excellent soils which have resulted from a commingling of boulder-clays and Permian rocks in the beautiful Vale of Eden. Again, it has already been noted that, in the central valley of Scotland, watered by the Forth and Clyde, and extending from the metamorphosed rocks of the Highlands on the north down to the uprising Silurian Lowlands on the south, the commingling of Old Red sandstones and

marls, Carboniferous shales and limestones, fragments of igneous rocks, and glacial detritus, has resulted in the formation of an arable soil which, under judicious cultivation, has attained a remarkable degree of fertility.

Mesozoic Series.—In giving an account of the soils lying on rocks of Mesozoic and Cainozoic age, the description will, of course, apply almost exclusively to England alone, and, roughly speaking, to that part of it which lies to the east of a line that may be drawn on the map from the mouth of the Tees to that of the Severn, the only notable portion west of this line being the Cheshire Plain. Beneath these younger rocks the older Palæozoic rocks of the West dip away eastwards (fig. 13), so that if a sufficiently deep boring were made in one of the eastern counties it would probably pierce, at last, the underlying Palæozoic beds. The Carboniferous strata which contain the coal-field of South Wales appear, in this way, to dip down under the younger beds of the counties between South Wales and Kent, and then, on the other side of the North Sea, to rise again in the Belgian coal-fields, thus forming a great synclinal curve. The recent finding of coal by a deep boring at Dover is quite consistent with, and indeed confirmatory of, this supposition. The strata now to be considered have not been violently contorted and disturbed like the older ones of the West, nor do they show indications of metamorphism. They are made up chiefly of alternating series of sands, sandstones, clays, and limestones, with all the intermediate forms of these sedimentary rocks.

The reader is already familiar with the Old Red Sandstone, a name over which Hugh Miller cast almost a poetic glamour by the fascinating description of his researches

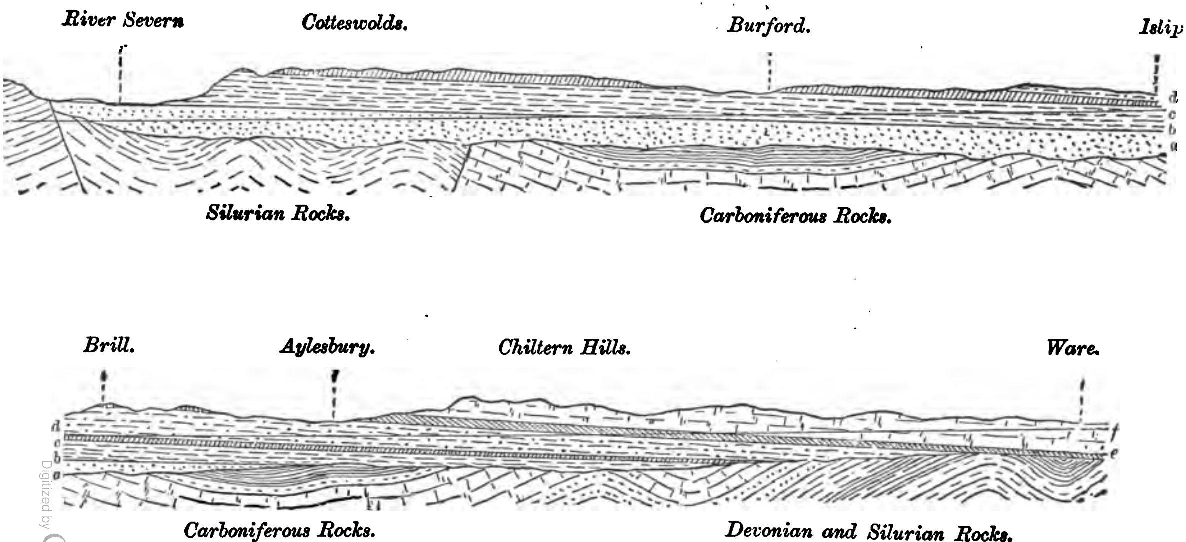

FIG. 13. DIAGRAM-SECTION FROM THE VALLEY OF THE SEVERN (GLOUCESTERSHIRE) TO THAT OF THE LEA AT WARE (HERTFORDSHIRE). DISTANCE ABOUT 108 MILES.

f, Chalk. *e*, Gault. *d*, Kimmeridge and Oxford Clays. *c*, Oolitic Limestones. *b*, Lias. *a*, Trias.

amongst the strata which are immediately antecedent to the Carboniferous series. The term New Red Sandstone was originated to denote all the red rocks that occur between the Coal-measures and the Lias, and to distinguish them from those which underlie the Carboniferous. Subsequently the New Red Sandstone was divided into—

Trias,
Permian,

and the term is now restricted to one section only of the upper of these two series. There is, however, a noteworthy similarity running through the Permian and Triassic series, which consist, in the main, of red, yellow, and variegated sandstones, conglomerates, and marls, with occasional beds of limestone. The group, states Mr. Woodward, forms a conspicuous band, stretching across England from the mouth of the Tees, near Redcar and Hartlepool, to the mouth of the Exe, with a branch running to the mouth of the Mersey, thus marking off the Palæozoic ground of the North of England, of Wales, and of the South-west of England from the Secondary and Tertiary tracts which lie to the east and south-east. Another area of the red rocks occupies the Vale of Eden, to the north and east of the Lake District. The Permian and Triassic rocks are, on account of their prevailing red colour, features of equal prominence in the landscape ; and the "red ground" and "red rocks" have given names to such places as Retford, Radford, Radcliffe, Radstock, and others, whilst in Worcestershire there is the village of Redmarley between Newent and Upton-on-Severn. The red cliffs between Seaton and Torquay impress all who see them ; while the red soils, and the deep red lanes, characterize the country at many places inland. The red colour of the rocks is in many cases due to the component par-

ticles having being coated with films of peroxide of iron during the deposition of the beds.

The term Trias originated in the circumstance that on the Continent of Europe this formation exhibits three distinct divisions, the Keuper, the Muschelkalk, and the Bunter. Although the middle group appears to be absent in England, the whole formation is nevertheless distinguished by the Continental name of Trias. Bunter means variegated, and Keuper is a provincial word used by the miners of Western Germany.

TRIAS.—The Bunter Sandstone, or New Red Sandstone, as it is also called, is seen in parts of Yorkshire, Cheshire, Lancashire, and Central England. The reddish and variegated sandstones often yield a deep, dry, sandy soil, the fertility of which varies according to the nature of the subsoil. When the latter is of clay, the overlying soil becomes cold and wet, and requires draining; when the underlying subsoil consists of marl or marly sandstone, it is worked in with the soil to form a rich red loam productive of luxuriant crops of every kind. The Keuper, or New Red, marls form fine rich meadows and pastures, the Cheshire cheese being the most noted product of the latter. The Trias, taken as a whole, is the most extensive formation seen on the surface in England; it extends, with some interruption, from Devonshire, through Somerset, Gloucestershire, and Worcestershire, to Warwickshire, where it divides into two branches, one stretching away through Staffordshire, across the fertile plain of Cheshire into Lancashire, and the other ranging northwards through the Trent Valley in Nottinghamshire, and along a strip of land in Yorkshire, to disappear beneath the sea at the mouth of the Tees. At its widest part, from Shropshire to Nottinghamshire, the Trias is eighty miles across from

east to west. The sandy soils on some parts of the formation are much improved by the application of marl from other parts, hence the number of old marl pits in the Keuper. The general fertility of the Trias may be estimated from the fact that the three highest rented counties in England rest chiefly on it, and it has the reputation of forming the best arable land in the country. In some parts of the New Red Sandstone, however, as in Cannock Chase, there are beds of conglomerate (pebbles cemented together into hard rock); and when these appear at the surface they break up into barren, gravelly soils, which are only brought under cultivation with extreme difficulty, and even now in some localities form waste land, as in Sherwood Forest. Other parts of the formation, again, have been overspread with glacial detritus, and in this case also the character of the soil has suffered; in the Vale of Clwyd, Denbighshire, however, where the New Red Sandstone is so overlaid, the result of the commingling is a very fertile soil. As in the case of the Old Red Sandstone, so in that of the New, orchard fruit-trees seem specially addicted to these red soils; and the cider produced by the Trias of Devonshire and Gloucestershire rivals that from the Old Red of Herefordshire.

The Bunter sandstone is one of the most prolific of the water-bearing strata. The Keuper marl, on the other hand, is not water-bearing. It is necessary, therefore, to penetrate the latter before a suitable supply of water is reached, and this is generally found in the underlying sandstones.

Jurassic.—Some of the richest agricultural areas of England are underlaid by rocks of Jurassic age. From the line between Axmouth and Weymouth on the south coast away to the coast line between Redcar and Filey, in Yorkshire, there stretches across England a broad irregular band of

strata, the older on the west and the younger on the east, and all dipping gently eastwards. This band attains its greatest width in the Midlands, where it extends from Rugby in the west, past Huntingdon and St. Ives, nearly to Ely in the east. Or, more to the south, it stretches across the country from Worcester to east of Bedford. The western and narrower part of this band consists of the outcrops of the Lias rocks, and the eastern and broader section of the outcrops of the Oolites. The Lias and Oolite are grouped together under the more general name of Jurassic, because they happen to be well and typically developed in the Jura district of the Alps. Taking a general view of these strata, they have been arranged by geologists in the order indicated in the table on page 10, and a good sectional view is seen in fig. 14.

LIAS.—The word "Lias" is usually regarded as a mere corruption of the term *layers*, and it came into use about a century ago. De la Beche recognised it, however, as the local term applied by the quarrymen of Somerset to the beds or layers of clayey limestone found in the lower part of the series to which the name of Lias is now given. The formation

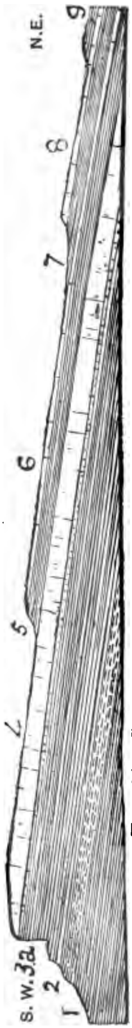

FIG. 14. SECTION THROUGH THE JURASSIC SERIES NEAR LINCOLN.

9. Oxford Clay.
8. Cornbrash.
7. Great Oolite Clay.
6. Great Oolite Limestone.
5. Upper Estuarine Clays.
4. Lincolnshire Limestone.
3a. Upper Lias Clay.
2. Middle Lias Clay.
1. Lower Lias Clay.

consists of thick beds of blue and yellow clay, with partings of sandy limestones and shales. The clay and shales are impervious to water; hence, near the outcrop of the porous strata of the overlying Oolite, the surface of the Lias is cold and wet, so that rushes, sedges, and other water-plants are its natural produce. Atmospheric influences cause the clays, shales, and limestones to break up into a soft but retentive clay soil, which resists the plough, and therefore is frequently unsuited to arable culture, even when drained. Nevertheless, though expensive to work, persevering industry has brought much of the Lias under the plough; and cereal crops may, in such cases, be raised to advantage. In some localities, as in Somerset, the flaggy limestones are so near the surface as to impede the plough From the very stiff character of the soil, and its persistent retention of moisture, however, a considerable extent of the Lias is devoted to grass land; and it supports some of the oldest pastures in the country, which, producing as they do beef and milk, cheese and butter, may well be termed "cheesy" pastures.

Stretching from Lyme Regis on the Dorset coast to Whitby on the Yorkshire coast, the Lias occupies extensive vales beneath the escarpments of the Oolite, whilst the harder strata of the Middle and Lower Lias again form escarpments overlooking other vales on the west.

The Lower Lias soil is brashy, sometimes loamy, and frequently of a rich brown colour. On it are raised wheat, barley, oats, cabbages, turnips, mangel, beans, and occasionally teasels. The ground is mostly flat, or gently undulating and forming open vales. Stilton cheese is yielded by the milk of cows grazed on the Lias clays near Melton Mowbray, in Leicestershire; double Gloucester cheese is the product of the Lias clays in the Vales of

Gloucester and Berkeley, where they form the rich fertile meadows on the Severn side; Cheddar cheese, again, is obtained from cows fed on the pastures resting on the Lias clay, New Red Marl, and Alluvium of Somerset. In some localities where the higher beds are exposed, the soil is very heavy, as in the Vale of Ilchester in Somerset, and the Vale of Marshwood in Dorset. The Lower Lias is not, as a rule, a water-yielding series, but throws up water where porous beds rest upon it.

The Middle Lias yields a rich soil formed by the decay of the Marlstone, which is a mixture of clay and sand with a considerable quantity of limestone. It forms, therefore, a strip of very fertile land overlooking the grazing lands of the Lower Lias. Apple-trees thrive on the Middle Lias of Somerset. The name of the county of Rutland (red land) is attributed to the prevailing colour of the soil; that on the Middle Lias is very fertile. The water-supply of the town of Northampton is derived from the beds of the Middle Lias.

The Upper Lias is less extensively developed than the lower members of the series. It is better known for the jet and the alum shale obtained from the strata of Yorkshire, and especially near Whitby, than for its agricultural features. Alum is now made from coal-shale so that the economic importance of the Upper Lias is less than it used to be. Still, the Upper Lias clay is largely used for making bricks, tiles, and drain-pipes.

As to the geographical distribution of the Lias, it must be apparent, from what has been said, that the Lias stretches as a very irregular strip from Lyme Regis, on the Dorset coast, to the mouth of the Tees, on the North Yorkshire coast. It extends, then, from Dorset, through Somerset, to Gloucestershire, in which county it forms

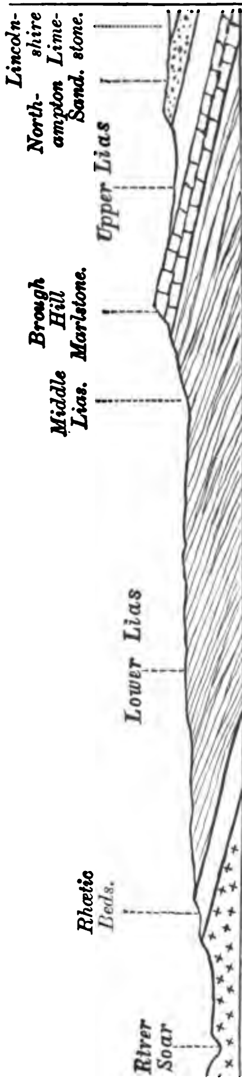

FIG. 15. GENERAL SECTION THROUGH EAST LEICESTERSHIRE: DISTANCE ABOUT 20 MILES.

under the shadow of the Cotteswolds, the dairy districts in the Vales of Berkeley, Gloucester, and Evesham; thence it stretches away through Worcestershire and Warwickshire into the counties of Northampton, Leicester, Nottingham, Lincoln, and York. Much of the milk which arrives daily in London is off the Lias. Fig. 15 illustrates a general section through East Leicestershire.

OOLITE.—The term Oolite originated with William Smith, the "Father of English Geology." It is derived from two Greek words (*oon*, an egg; *lithos*, stone), and is applied to limestones built up of small rounded particles of calcareous matter, cemented together and resembling the roe of a fish. Most of the limestones of the Oolite series possess this structure, which is well seen in the Inferior Oolite, the Great or Bath Oolite, and the Portland Oolite. Pisolite, pisolitic limestone, and peagrit are names given to oolitic rocks, the particles of which approach the size of a pea or a bean. The

great Oolitic formation does not consist exclusively of limestones, however, there being several important argillaceous members, such as the Oxford and Kimmeridge Clays, besides arenaceous strata, as seen in the Midford and Northampton sands. Fissile sandy limestones, locally but incorrectly called slates, such as the Stonesfield Slate, also occur. The English Oolites exhibit considerable local modifications, and it is no easy matter to exactly correlate them as seen, for example, in the South-west of England, in the Midlands, and in Yorkshire. Trending in an irregular line on the east of the Liassic outcrops, from the coast of Dorset to that of Yorkshire, they form fine bold hills, well exemplified in the Cotteswolds of Gloucestershire, the Cliff of Lincolnshire, and the Hambledon and Howardian Hills of Yorkshire. The limestone beds are seen as prominent ridges above the clay vales of the Lias, and nowhere is a better example afforded of escarpments than to the railway traveller who looks eastward from the Severn valley between Gloucester and Cheltenham. The Oolites form much of the hilly ground which underlies the Yorkshire moors, whilst in the Midland and Southern counties they are overlaid by rich corn-lands and pastures.

The Midford Sands, so called from a village some three miles south of Bath, are micaceous yellow sands with calcareous concretions. They crop out in Dorset, Somerset, and Gloucestershire, and support generally a fertile soil. They were formerly called the "Sand of the Inferior Oolite," and they form conspicuous grassy knolls near Bridport, still better examples being seen in Glastonbury Tor and Brent Knoll. Farther north, the Northampton Sand yields a fairly rich soil.

The Inferior Oolite is seen in its highest degree of

development in the Cotteswold Hills of Gloucestershire, especially around Cheltenham, whence it stretches northward to Bredon Hill, in Worcestershire, eastward to Sarsden, in Oxfordshire, and southward to Sherborne, Yeovil, and Bridport, in Dorset. The soil is reddish brown and brashy, and the generally hilly ground is sometimes almost barren, though good corn land is met with where the soil is sufficiently deep. The Cotteswold Hills were long in a state of natural pasture, and chiefly grazed by sheep; much of this district is now under the plough, and roots, clover and cereals are grown even on the summits of the hills, though the soil is mostly thin, poor, and brashy. The prevailing timber-tree on the Cotteswolds is the beech, which prefers a limestone soil; the ash and the elm grow less freely, while the oak, which luxuriates on the Lias clays, is scarce on the Oolites of the Cotteswolds.

The Lincolnshire limestone, a section ot the Inferior Oolite, yields a light soil not of much value; but good barley is grown in some districts.

The Fuller's Earth is a clayey deposit of only local interest. The land is usually heavy and wet, and not very productive, but on the slopes of the Cotteswolds the loose Fuller's Earth rolls down on to the soil of the Inferior Oolite, the fertility of which is improved by the admixture.

The Great or Bath Oolite is a shelly limestone which supports a thin stony soil, not difficult to work, but too elevated and not deep enough for productive cultivation. It is best adapted to turnips and barley, but wheat is also grown on it. It is chiefly seen around Bath, in Gloucestershire, and on the borders of Oxfordshire.

The Forest Marble and Cornbrash soils are of a clayey

nature, due to partings of clay between the flag-like beds; though poor, they may be greatly improved by drainage and cultivation, and then yield fair crops of cereals, pulses, and roots. The Cornbrash, though but a thin deposit, is remarkably persistent across England. As its name indicates, it is well suited to the growth of corn. In the southern counties its outcrop is occupied by a line of villages which have thus been located, not only on account of the fertility of the Cornbrash, but by the circumstance that this porous rock, resting, as it does, upon the impervious Forest Marble, is a collecting-ground for water.

The clays of the Oolite form close, sticky, sometimes calcareous soils, scarcely adapted for arable land, but producing, after thorough drainage, rich pastures not unknown for the quality of their dairy produce. The Oxford Clay, which in some localities is twenty miles wide, joins the Kimmeridge clay in Huntingdonshire; and in Lincolnshire they appear to be one continuous formation. The name Oxford Clay was given by Conybeare in 1822. Commencing near Weymouth, the Oxford Clay stretches across the Vale of Blackmoor, past Trowbridge and Melksham, to Chippenham, and from Wiltshire into Oxfordshire, in which latter county it attains its greatest development. From Oxford the outcrop extends to Bedford and Huntingdon, and it underlies much of the western portion of the Cambridgeshire fens and those which adjoin Huntingdonshire. Still farther northward the Oxford Clay is seen near Scarborough. So stiff and stubborn a clay is best in permanent pasture, and this is the case upon most of the area. To obtain well-water it is necessary to sink through the Oxford clay into the underlying Kelloway rock. The cheese of Stilton in

Huntingdonshire, the North Wilts cheese, and the blue Dorset cheese, are the produce of the Oxford clay.

The Corallian series, including the Coral Rag, is unimportant. The soil is of a light brashy character, yielding but poor pasture. These beds are usually water-bearing strata.

The Kimmeridge Clay is of a dark bluish-grey colour, and is more or less shaly. It is named after Kimmeridge (or Kimeridge), in the Isle of Purbeck. It has an extensive outcrop, trending from south-west to north-east. It is well developed in Dorset, and in Wiltshire it forms the wide expanse of North Wilts Clay, between Westbury and Devizes. In the counties of Oxon, Bucks, Hunts, Lincoln, and Yorkshire, it is also well seen. The cold, stiff clay forms broad vales with naturally unproductive soil, so that most of the land is under grass. The Aylesbury dairy district rests chiefly on the Kimmeridge Clay. Springs are scarce. Oaks, always partial to clay, grow well upon this formation, to which, therefore, William Smith gave the name of Oak-tree Clay. The fen-land, occupying the Bedford Level and a considerable part of Lincolnshire, rests upon a thick deposit of clay, which has been named the Fen Clay. In its lower portion this belongs to the Oxford Clay, and in its upper layers to the Kimmeridge Clay.

The Upper Oolites are mostly in old pasture, being too expensive to work; good arable land only resulting where clay and sandy limestone crop out together. The Portland Beds form bold hills which are usually reserved as sheep walks.

Regarding the Oolite as a whole, it occupies a strip of land very similar to the Lias, and lying on the east of the latter; commencing on the Dorset coast, it extends

through parts of the counties of Somerset, Wilts, Berks, Gloucester, Oxford, Bucks, Beds, Hunts, Rutland, and Lincoln, and dies away on the south side of the Humber, the clays re-appearing in the North Riding of Yorkshire, west of Scarborough. In Northamptonshire the nature of the outcrop is such (see p. 103) that the Lias and Oolites ramify amongst each other very curiously, producing the fertile districts around Rockingham and Kettering. In the Oolitic strip, thus stretching from Dorset to Yorkshire, the younger or upper members of the series, notably the clays, are on the east side; thus, Huntingdonshire is occupied almost entirely by clay. The greatest breadth of the Oolites is along a line drawn from Stroud, through Oxford, to near Aylesbury.

The CRETACEOUS system, equally with the Jurassic, comprises a series of strata of very varied lithological character. Sands and clays in the main prevail; but as the group includes the Chalk, the name Cretaceous (Lat. *creta*, chalk) was applied to the entire system. Collectively, these Cretaceous strata occupy a very considerable proportion of the area of agricultural England, as they extend in a broad band from Norfolk in a south-westerly direction to Wilts and Dorset, and from Wilts eastward to the coast of Kent and Sussex. They also occur in Lincolnshire and in the East Riding of Yorkshire, where they flank on the west the alluvium of Holderness.

WEALDEN.—Of the Wealden group the lower series, or the Hastings beds, consist chiefly of fine sand, interstratified with lesser beds of clay; they produce a fine dry sandy loam, which, in dry weather, becomes quite a dust. Where the clay and calcareous sandstone weather down together, a light productive soil results. But where the fine siliceous sand contains nodules of iron ore, a poor wet

soil, producing naturally heath and furze, prevails. The Hastings Sand occupies the middle of the Weald district in Kent and Sussex, where the steep-sided wooded valleys are called "gills," a term quite characteristic of the Weald, but in common use also in parts of Yorkshire and other northern counties.

The younger member, the Weald clay, forms a fringe round the Hastings beds on the north, west, and south; its width varies from five to twenty miles, and it is seen in Kent, Surrey, and Sussex. The soil it supports is a damp, stiff, yellowish, siliceous clay, which is used in some localities for making bricks; indeed, so well is it adapted for this purpose, that it sometimes dries in the sun as hard as a brick, and therefore it requires a considerable outlay to bring such a soil into good condition, thorough drainage being the first requisite. Nevertheless, some parts form a very active arable soil, yielding wheat, oats, beans, and roots; and here and there deep loams support some of the finest hop-gardens; much of it, however, is in pasture. East of Tonbridge occurs the great spread of loam supporting the hop lands for which the district is celebrated. Down to within recent times most of the area occupied by the Wealden and Hastings beds was covered by forests, some of which still remain. This accounts for the termination *hurst*, so common in the local names—Wadhurst, Goudhurst, Speldhurst, Penshurst, Ticehurst. From this circumstance too, the district received its name of Weald or Wold, meaning a woodland. The area is noted for its oak-trees, so that the Weald Clay, like the Kimmeridge, received from William Smith the name of Oak-tree Clay, a term also sometimes applied to the overlying Gault. Besides the sand beds included in the Weald Clay there also occur layers of limestone full

of shells—the so-called Sussex, Potworth, or Bethersden marble. In Yorkshire the Speeton Clay is, in part, the representative of the Wealden strata of the south-east of England.

In his exhaustive memoir on the agricultural geology of the Weald, Mr. W. Topley states that, generally speaking, the Wealden area proper is characterized by a superabundance of hedgerow timber, by broad strips of underwood called "shaws" in place of hedges, and by small fields and badly kept roads.

LOWER GREENSAND.—The Lower Greensand forms a very narrow fringe along the north, west, and south of the Weald Clay, just as (fig. 16) the latter surrounds the Hastings Sand; it also extends as a narrow strip on the east of the Oolite from Dorset up to Norfolk, and occupies a similar position in Lincolnshire and Yorkshire. Its soil is generally very siliceous, and frequently mingled with silicate of iron; it is therefore often barren, and considerable areas are in common-land, covered with heath and fir. Where it becomes calcareous, as near Hythe, it is dry and productive, hops especially yielding good crops. Mr. Topley states

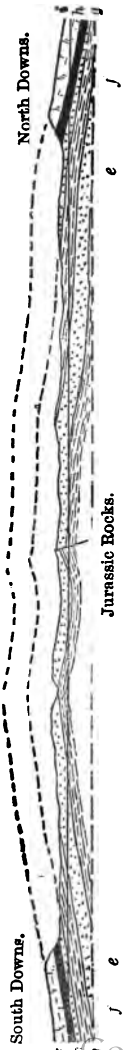

FIG. 16. DIAGRAMMATIC SECTION ACROSS THE WEALDEN AREA OF KENT: DISTANCE ABOUT 50 MILES, VIEWED FROM THE EAST.

i, Chalk. g, Lower Greensand. e, Hastings Sand.
h, Upper Greensand and Gault. f, Weald Clay.

that the lowest division of the Lower Greensand, the Atherfield Clay, should be classed lithologically with the Weald Clay, but it is separated on account of its fossils. It is a stiff brownish clay, sometimes with limestone beds. The most important member of the Lower Greensand series is the Hythe beds; it occupies the largest area, forms the most fertile soil, and yields the most valuable economic products. Throughout Kent it consists of beds of limestone (Kentish Rag), and of a calcareous sand or soft sandstone, known as "hassock." An admixture of brick-earth with the ragstone soil is highly fertile.

The Woburn Sands, near Woburn, received about a century ago the name of the "Sand of Bedfordshire." They are of Lower Greensand age, and are of interest in connection with the Experimental Farm which the Duke of Bedford has placed at the disposal of the Royal Agricultural Society of England. Professor Bonney points out that at Sandy, Bedfordshire, the Lower Greensand strata form a remarkably picturesque escarpment on the right bank of the Ivel; between that place and Potton they are cut through by the railway from Bedford to Cambridge. They consist of Carstone, and of buff or ochreous yellow sand. So sterile is the land in places that it supports little besides Scotch fir; and the extraordinary productiveness of the market-gardens in the Ivel valley above Sandy is largely due to the admixture of this light warm sand with the alluvial soil. The "coprolites" found in the Lower Greensands of Buckinghamshire and Bedfordshire consist of wood mineralized by phosphate, casts of molluscs, bones, and shapeless lumps; they are worked for manure. The Potton phosphatic nodules yield from 30 to 50 per cent. of phosphate of lime, and

those of the Cambridge Greensand from 58 to 61 per cent.

GAULT.—The Gault and Upper Greensand form yet another border round the Wealden area, separating the Chalk on the outside from the Lower Greensand on the inside; these beds are also seen in Dorset, in the southern half of the Isle of Wight, and as a fringe on the east side of the strip of Lower Greensand which, as already stated, extends from Dorset to Norfolk, and through parts of Lincolnshire and Yorkshire. The word Gault is a local name in Cambridgeshire for an unctuous clay. The Gault is generally a bluish, sometimes greyish, calcareous clay, forming a strong, tenacious, stubborn soil, which is best subdued by draining and applying some of the overlying Greensand; useful crops of cereals and pulses may then be obtained. Much of it is in pasture, and it is known in some localities as "blackland." South-east of Calne, in Wiltshire, is a village called Blackland, which is situated partly on the Gault. The soil is driest where it is covered by drift or alluvium, this being the case where the Gault is crossed by rivers on their way to pierce the Chalk escarpment. In some places it is so very impervious that the water remains on the surface, as in the Vale of White Horse, Berkshire. The areas occupied by the Gault are generally flat and marshy, but in many localities oaks thrive upon it. The middle portion of the outcrop is the most productive, as it contains the greatest percentage of carbonate of lime and is practically a marl.

UPPER GREENSAND.—The Upper Greensand consists of soft, friable, calcareous sand, of a dirty green colour, due to glauconite; and it yields a dry soil, excepting where the underlying Gault Clay throws up water. The soil, especially where it is the joint product of the Upper Greensand and

the overlying Chalk Marl, is one of the richest in the country, and is easily cultivated. Where it becomes too light, an addition of Gault clay is the natural remedy. Its great fertility is due to the presence of phosphatic nodules, or "coprolites," which provide a supply of phosphorus, for which most soils are dependent on expensive manures, as superphosphate of lime, bone-dust, and guano.

The Malm rock (or firestone) is a local term used in Sussex, Hants, and West Surrey, to denote a hard, pale, calcareous sandstone of the Upper Greensand. The rich hop-district of Farnham, Surrey, is on this rock. In Hants, at Hartley, near Selborne, it forms a cliff overlooking the softer beds of the Lower Greensand and the flat areas of the Gault woods, called "Hangers," growing on the sides of the cliff.

There is a rich tract of Upper Greensand in Bedfordshire; and other tracts occur in Bucks, Oxon, Wilts, and Somerset.

Chalk.—The lowest member, the Chalk Marl, especially where it approaches the Upper Greensand, supports, like the latter, a most excellent soil, which produces fine crops of roots, pulses, and cereals. To the Chalk itself less praise can be given, as its soils at the best are only of moderate fertility. The limestone of the Lower Chalk is of a dingy white colour, owing to the presence of iron and clay; the Upper Chalk beds are whiter, and are freely interspersed with flints, which are usually of a black colour. The Chalk naturally produces short, thick pastures, to which sheep are addicted. In the north it forms the Yorkshire and Lincolnshire Wolds; in the south it rises into the North and South Downs, the soil being very thin, so that the Chalk itself is within one or two inches of the grass. A good illustration of the difference between transported soils and indigenous or local ones is afforded

by a comparison of the Chalk of the Lincolnshire Wolds with that of the North and South Downs. In the former locality it is mostly covered (fig. 17) with superficial deposits such as Boulder Clay, with glacial sands and gravel; in the latter this is not the case, consequently the Chalk of Lincolnshire has not the bare and arid appearance associated with this formation in the southern districts, and most of it has been converted into useful arable land. The Upper Chalk is more especially the region of sheep-walks, the Lower member yielding more arable land. Excellent crops of barley are, in favourable seasons, grown upon the Chalk areas of South Wilts, besides good crops of turnips, upon which sheep are folded. In some localities water has dissolved out much of the carbonate of lime from the soil, and left on the Upper Chalk a loose, flinty soil, and on the Lower Chalk a cold, stiff clay, such as may be seen in the counties of Kent, Surrey, Hertford, Berks, and Wilts. The soil resulting from a mixture of the Lower with the Upper Chalk is said to yield good root crops, especially of carrots, after deep forking. In Suffolk, West Essex, and East Hertfordshire, as in Lincolnshire, to which reference has been made, the

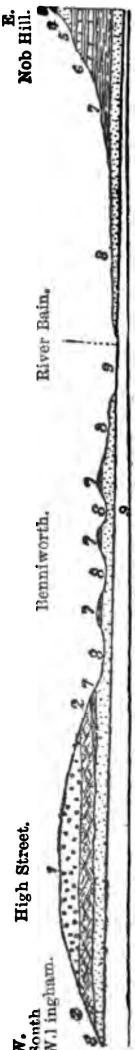

Fig. 17. Section through the Lower Cretaceous Series of Lincolnshire, near Donnington: Distance 3 Miles.
x, Sea Level. 1. Boulder Clay. 2. Glacial Sand and Gravel. 3. Lower Chalk. 4. Red Chalk. 5. Carstone. 6. Tealby Limestone. 7. Donnington Clay. 8. Spilsby Sandstone. 9. Kimmeridge Clay.

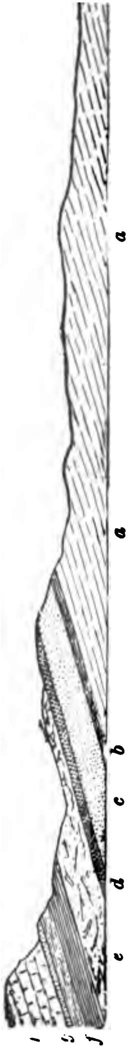

FIG. 18. SECTION THROUGH THE CRETACEOUS ESCARPMENTS OF SURREY: DISTANCE ABOUT 9 MILES: VIEWED FROM THE WEST.

h, Chalk. g, Upper Greensand. f, Gault. e, Folkestone Beds. d, Sandgate Beds. c, Hythe Beds. b, Atherfield Clay. a. Weald Clay.

agricultural qualities of the soil are entirely altered, owing to the surface of the Chalk being covered by glacial detritus. Besides the counties already mentioned, the Chalk is seen in those of Sussex, Hants, Dorset, Oxon, Bucks, Cambridge, and Norfolk, the lowest rented counties in England being on its soils. Because of the porous character of the rock, many of the ponds used to supply animals with water in Chalk districts require to be lined with clay. On account of the scarcity of water on the Chalk, wells are sometimes sunk to a depth of 200 feet or 300 feet before reaching the water level. At the base of the Chalk escarpment (fig. 18) strong springs frequently occur; and, after much rain, streams for a time run down some of the valleys, but are inconstant. They are due to a temporary rise of the level of the water-table in the rock, and are called *bournes*—"nailbournes" in Kent, "winterbournes" in Wilts and Dorset, and "gipsies" in Yorkshire. In Wiltshire several villages include Winterbourne in their name, for example, Winterbourne Gunner. At the bottoms of the dry valleys beds of flint, mingled with chalky loam, make an excellent soil. Water

lying on clayey land, resting upon Chalk, may be discharged through wells into the Chalk below. In Hertfordshire chalk is obtained by sinking shallow pits through the overlying clay; and these pits are afterwards used as outlets for drains. The presence of flints in the Upper Chalk and their absence in the Lower Chalk cannot be accepted as invariably the case. Flints are largely employed as road-metal; but if used fresh from the chalk-pits, they are found to be brittle, and far less durable than when allowed to weather for a few years in order to acquire toughness. The best flints for road-mending are those picked off the fields; and on the arable sheep-farms of the Upper Chalk districts of Wilts and Hants, a good crop of flints can generally be secured after a field has been folded by sheep, the treading of the animals bringing the flints to the surface—in shepherds' parlance, causing them to "grow."

Chalk is largely burnt for lime, and it is also applied in the raw state to land. Even within the Chalk area itself it is no uncommon sight in winter to see a field, resting upon the Chalk, top-dressed with this rock. The reason is, that the soil, of local origin, consists of the non-calcareous residue of the Chalk-rock, from which, as is noted above, the carbonate of lime has been dissolved out by the action of rain-water. The stiff red or blackish clay, known as "clay with flints," is thus a residue of the decomposition of the Upper Chalk, and, in the southern counties, is frequently improved by a top-dressing of chalk. The hollows in the chalk, called "pipes," or "sand-galls," which can often be seen on the side of a pit or of a railway-cutting, arise from the dissolving of the chalk-rock and the falling in from above of the overlying sand or gravel to fill up the space thus formed.

Probably no part of England has undergone less alteration during the last thousand years than the Chalk Downs; and the area occupied by them is but little more populated now than it was in Saxon times. The visitor to Stonehenge who gazes in every direction upon the wide rolling expanse of bare Downs which stretch between Salisbury and Devizes, is impressed by nothing more than by the solitude which prevails. A flock of sheep may be seen grazing the short herbage here and there; but the barking of the sheep-dog is the only accompaniment to the quaint "music" of the sheep-bells. The term "hazel" is applied to the soils of the higher parts of some of the Downs —light, dry, friable, sandy loams, of moderate depth, resting upon chalk rubble, or partially dissolved chalk, and affording in their natural state short but sweet sheep pasturage, but liable on the brows and sides of the hills to be washed away when under cultivation. In Dorset the soil on the more elevated parts of the Chalk district is a thin loam resting on rubbly chalk; and where the soil is only two or three inches deep the land cannot be ploughed to advantage, as the mixture with the loose chalk is injurious. The poorest parts of the Downs are the steep acclivities overlooking the Vale of Blackmoor, and the most fertile are those which border the sandy (Eocene) district between Wimborne and Dorchester. Wherever the strata incumbent on the Chalk consist of deep sand and gravel the surface is generally covered with furze or heather, the latter seldom appearing where the Chalk is only at a shallow depth.

Where timber grows upon the Chalk, beech is the characteristic tree. Juniper is often abundant, as also are yews that have weathered the storms of centuries. Box frequently grows on the face of the Chalk escarpment, as is the case at Box Hill and Boxley.

In the Chalk Marl of Cambridgeshire, between Cambridge and Hitchin, "coprolite" beds have been extensively worked; and there are also coprolite-diggings at Shillington, in Bedfordshire, and at Ashwell, in Hertfordshire. The phosphatic nodules, which are extracted by washing, yield about 300 tons per acre, and are worth some fifty shillings a ton. The diggers usually pay about £140 an acre for the right of digging, and at the end of two years the land is returned properly levelled and re-soiled.

Respecting the origin of phosphatic nodules, such as occur in the Chloritic Marls of the Chalk, Prof. Bonney has offered the following explanation. He points out that phosphate of lime is present in small quantities in the sea, in several rivers, and in numerous mineral springs; it is found in many plant and animal remains; and, in the form of apatite, it is met with as a mineral in many rocks. He considers that the phosphatic nodules are due to concretionary action, and have been formed by segregation out of mud saturated with phosphate of lime. The "coprolites" in the Chloritic Marl of Cambridge he regards as derived from more extensive deposits of Gault age.

The Chalk extends from England to the Crimea, and from Bordeaux to the Baltic.

Cainozoic Series.—Above the Chalk occur a series of more or less loose aggregates of rocks comprising sands and gravels, clays and marls, but few limestones. They are altogether softer and less consolidated than the strata of the underlying secondary series, between which and the deposits now in course of formation they constitute a transition group. The English Tertiaries are confined

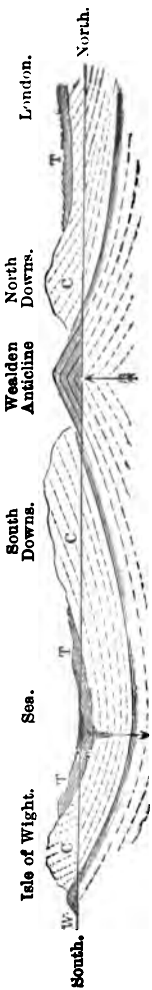

FIG. 19. IDEAL SECTION FROM LONDON TO THE SOUTHERN COAST OF THE ISLE OF WIGHT.
T, Tertiary Series. C, Chalk. W, Wealden.

to a somewhat limited area in the eastern and southern counties, and only the Eocene and Pliocene formations call for special notice.

EOCENE.—The metropolis stands on this formation (fig. 19), which stretches from the Essex coast, far up the Thames valley, to the borders of Wiltshire. Another tract on the south coast occupies parts of Dorset, Hants, and Sussex, and the northern portion of the Isle of Wight (fig. 20). The lowest member of the Eocene series, comprising the Woolwich and Reading Beds and Thanet Sands, was once known as the Plastic clay, and it forms wide heaths in Hampshire and Berkshire. The light sandy soil suffers from the presence of alternating beds of clay, which throw up much water; to bring the soil into condition requires thorough draining, subsoil ploughing, and addition of some of the neighbouring chalk. The natural produce is heather, furze, and a poor grass, almost valueless.

Professor Prestwich recognises three types of the Woolwich and Reading beds. Firstly,—as seen in the Hampshire Basin, and in the London Basin all along the northern outcrop, and on the western part of the southern outcrop through North

Hants and most of Surrey,—the series is made up of mottled and plastic clays, and of many-coloured sands, with loams. Secondly,—in the eastern border of Surrey, in West Kent, the border of East Kent, and partly in South Essex,—they comprise grey clays and light-coloured sands. Thirdly,—in East Kent,—they take the form of sharp, light-coloured sand.

The London Clay, which received its name from William Smith in 1812, has a bluish or brownish tenacious, occasionally loamy soil, which splits in dry weather, and so assists drainage. Much of it is in pasture, and it serves this purpose well, but is too strong for roots, though it yields, after marling or liming, fair crops of corn and beans. Elm, oak, and ash thrive upon it. As the London Clay is impervious to water, the wells in and around London have to be sunk into the basement beds; they are therefore deep, excepting where the water is derived from superficial gravels lying on the London Clay. It occupies the London basin, and

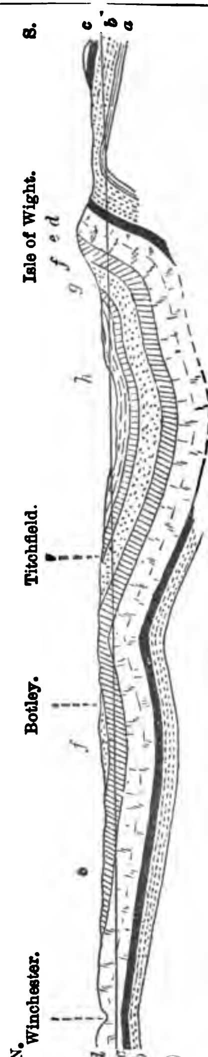

FIG. 20. SECTION THROUGH THE HAMPSHIRE BASIN AND THE ISLE OF WIGHT: DISTANCE ABOUT 35 MILES.
h, Oligocene. g, Upper Eocene. f, Middle Eocene. e, Lower Eocene. d, Chalk.
c, Gault and Upper Greensand. b, Lower Greensand. a, Wealden.

stretches from Windsor, in the west, to Harwich, on the Essex coast, and to Reculver, on the coast of Kent; and from north to south it extends from Barnet, in Hertfordshire, to Croydon, in Surrey, its greatest width being about twenty miles.

The Bagshot Sands appear next above the London Clay; they occur to the south-west of London, on the sterile Bagshot Heath, and on the coast of Hampshire. Their soil is poor, light, and sandy, and is little cultivated, much of it remaining in heath or moorland, as in the New Forest. Most of the "Greywethers" were derived from the Bagshot Sands, though some came from the Reading Beds, or the basement-bed of the London Clay. They occur in the southern and south-eastern parts of England, and are relics of the Tertiary rocks which once covered the Chalk Downs. They are concretionary masses of sandstone which have been hardened by siliceous cement, and they have received the name of "Greywethers" from their vague resemblance in the distance to sheep. Other names are Sarsen Stone, Sarsden Stone, Druid Sandstone. The outer ring of Stonehenge is built of huge Greywethers.

PLIOCENE.—The Pliocene strata occur in the extreme east of England, extending along the coasts of Norfolk and Suffolk, and partly into Essex. They consist of shelly sand, gravel, and laminated clay. The word "Crag" is a Suffolk term for the gravel, the shelly parts of which used to be dug as "marl" for agricultural purposes. The soils are sometimes so loose that after ploughing they become drifted by the wind; and after hot dry weather the crops are light and almost scorched. These Crags form the repository of phosphatic nodules similar to those of the Upper Greensand, and as much as £70 an acre has been given for the right to dig over a two-acre field in

search of these valuable mineral fertilizers, the land itself reaping much benefit from the process. Coprolites, yielding from 45 to 60 per cent. of phosphate of lime, have been dug near Bawdsey, Boyton, Butley, Shottisham, Sutton (fig. 21), and other parts of the Suffolk Bone-bed. The eastern counties are essentially the corn-producing districts of England.

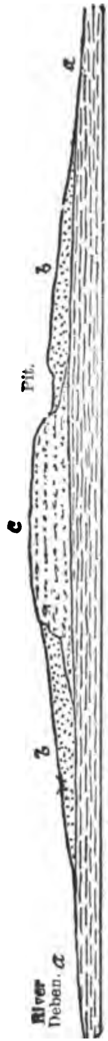

FIG. 21. SECTION NEAR SUTTON, IN SUFFOLK: DISTANCE ABOUT HALF-A-MILE.

a, London Clay. b, Red Crag. c, Coralline Crag.

ALLUVIUM AND DRIFT.

ALLUVIUM.—Alluvial deposits are usually formed on the banks, and at the mouths or estuaries, of rivers. They consist of the silt and mud, gravel and sand, brought down by the waters of the river; and being thus composed of the well-mixed detritus worn from the various formations which the river-system drains, they are usually very fertile, forming rich meadows and pastures. In Lincolnshire the process termed *warping* consists in allowing the waters of the rivers to flow over the land for the sake of the fertilizing deposit. In Egypt, again, the cultivation of the soil is entirely dependent on the periodic overflow of the Nile, for there is no rain. In England, alluvial soils occur on the banks of the Ouse, Derwent, Trent, and Humber, in the York and Lincoln district; on the banks of the Thames; and on those of the Bristol Avon, Monmouthshire Wye, Usk, and Severn, terminating in the broad flats bordering the Bristol Channel. The "haughs" of Northumberland are likewise of alluvial origin. Under this head mention must be made of vegetable accumulations, such as peat-mosses, bogs, and swamps. Of the flat, undiversified country round about the Wash Sir A. C. Ramsay has given us a graphic picture.[1] On the west coast of Lancashire, in the estuary

[1] The great plain of the Wash consists partly of peat on the west and south, but chiefly of silt. These broad flats, about seventy miles in length from north to south, and forty in width, include an area of

of the Ribble, the Fylde plains somewhat resemble those of the Wash. One of the greatest difficulties experienced in reclaiming alluvial tracts is that of drainage, as in the case of the unmanageable peaty soils of Scotland and North-west Ireland. If, however, this has been successfully accomplished, a fertile soil is the almost certain reward. Thus the flat country known as the Bridgwater Levels, in Somerset, consisted, at the beginning of this century, of wet useless bogs; by efficient drainage, and top-dressing with river-mud, it has been gradually reclaimed, and now forms grazing-lands of the richest description, clovers and pasture-grasses thriving where

more than 1,700 square miles. The whole country is traversed by well-dyked rivers, canals, drains, and trenches. Standing on the margin of the flat, or walking on the long straight roads or dykes, cheerfulness is not the prevailing impression made on the mind. The ground looks as level as the sea in a calm, broken only by occasional dreary poplars and willows, and farm houses impressive in their loneliness. The soil of these fens, ere the crops grow, is often as black as a raven, the ditches are sluggish and dismal, and the whole effect is suggestive of ague. Windmills of moderate size stand out from the level as conspicuous objects; and here and there the sky-line is pierced by the ruins of Crowland Abbey, Boston Tower, and the massive piles of the Cathedrals of Ely and Peterborough on the margins of the flat. Yet it is not without charms of a kind; as, when at sunset, sluice and windmill, and tufted willows combined with light clouds dashed with purple and gold, compose a landscape such as elsewhere in Western Europe may be seen in the flats of Holland. The same impression, in less degree, is made on the banks of the Humber, where the broad warped meadows, won from the sea by nature and art, lie many feet below the tide at flood, for, walking in the fields behind the dykes, when the tide is up, good-sized vessels may be seen sailing on the rivers above the level of the spectator's head. An old and entirely natural loamy silt, somewhat of the same character, follows the course of the Ouse, and to a great extent, covering the fertile Vale of York, passes out to sea in the plains that border the Tees.—*Phys. Geol. Gt. Britain.*

once the bog-plants held undisputed sway. When a peaty soil is drained, the heaths disappear, and the Yorkshire fog or soft grass, Holcus lanatus, L. takes, at first, their place. Under alluvial soils must also be classed the *brick-earth*, or *wash*, consisting of the detritus worn from hill-sides, down which it rolls to produce fertile accumulations in the plains below.

DRIFT.—This term is used to denote, amongst other things, the detritus which was scattered broadcast over much of the British area during the latest Glacial Period. The ice in its progress may have eroded some of the rock on which the drift—Boulder-clay or Till, for example—rests, and a mixed soil then results. And further, as the glaciers ground up the surface of the land over which they flowed, the detritus of one formation was mingled with that of another, and the result of this is usually beneficial. The Drift necessarily forms *transported* soils; and, as the reader must have noticed, the soil in such cases differs more or less from the subsoil. In some, more especially the southern, parts of Britain, the Drift is absent, and then there is a close and intimate relation between the nature of the soil and that of the rock below —the subsoil.

On this subject, Mr. H. B. Woodward says, "The occurrence of stones and boulders far removed from their parent source early attracted the attention of geologists; but for a long period the phenomena, now known as of glacial origin, were unexplained, and the Drifts were looked upon as little more than 'extraneous rubbish,' the product of geological agents quite distinct from those which helped to form the more 'solid' rocks that underlie them. Inasmuch as, in certain places, they rival in thickness some earlier geological formations, and as, taken

collectively, they have a more direct influence on Agriculture than any other strata, their importance may readily be conceded. The interest now taken in these superficial deposits was mainly aroused by Joshua Trimmer, who commenced to map the Drifts on the One-inch Ordnance Map; and he was followed by Mr. S. V. Wood, jun., to whose enthusiastic labours we are most largely indebted for the foundation of our knowledge on this subject. It is, however, impossible to indicate with accuracy the distribution of the Drifts, on a map smaller than the One-inch Geological Survey Map; and with the exception of the Alluvial marshes, they occupy a comparatively insignificant part in the scenery of our country, for the main features were marked out before the Drifts were accumulated."

At the end of 1883 the Geological Survey of England and Wales, on the scale of one inch to a mile, was completed. This work was, however, concerned only with the "solid" geology, with the deposits of river and marine alluvium, and with accumulations of peat. Other extensive deposits, of which mention will presently again be made, and which enter largely into the constitution of soils, were ignored, the fact being that the industrial and scientific importance of mapping these superficial accumulations was not recognised until comparatively ecently. Geologists had not adequately grasped the extent and significance of these surface deposits; and the geological agencies involved in their production were not fully understood during the earlier years of the field survey for the one-inch map, that is, the map constructed on the scale in which one inch represents one mile. In the light of fuller knowledge, however, the necessity of mapping the more or less heterogeneous accumulations

of mineral matter, or detritus, which rest upon the denuded edges of the regularly stratified rocks beneath, became apparent; and accordingly, in 1871, the publication of what are termed the "drift" maps was commenced.

ORIGIN OF THE DRIFT.—To rightly understand the origin and the relations of the Drift, it is necessary to glance, though ever so briefly, at some recent events in the geological history of the British Isles.

The Tertiary or Cainozoic period of the earth's history is, according to the present state of geological knowledge, divided into the following minor periods :—

4. Pliocene.
3. Miocene.
2. Oligocene.
1. Eocene.

The Eocene is represented by a series of strata in the Isle of Wight and Hampshire, but chiefly in the Thames Valley, the London Clay being the most important. The Oligocene beds are restricted mainly to the New Forest and Isle of Wight areas. The Pliocene or Crag deposits are seen in the extreme east of England, in Norfolk and Suffolk; and they afford abundant palæontological evidence that, during the period of their deposition in comparatively shallow water, the climate of this part of the globe was undergoing a gradual refrigeration. The cold subsequently became so intense that, over most of the British area, the heat of the summer sun was insufficient to melt the winter snows, and thus there gradually accumulated over much of Great Britain and Ireland a thick and extensive ice-cap, similar to that which persists in Greenland to the present day. As the glaciation became more intense, the great ice-sheet would increase in volume and

in weight; and as it slowly flowed along the surface of the land it would produce a two-fold effect, firstly, in grinding up the surface of the ground over which it passed; and secondly, in carrying with it, and stranding or depositing far from their place of origin, ice-worn blocks or boulders (erratics). In this way was accumulated the Lower Boulder Clay, a stiff clayey deposit full of transported blocks of stone, some of the latter enclosed in the Boulder Clay of Holderness, in Yorkshire, being derived from certain syenitic rocks in Norway, while fragments of granite, gneiss, and schists in the Boulder Clay of Norfolk also came from the higher latitudes of Northern Europe—borne thence on the bosom of the ice sheet.

As it is doubtful if there are any rocks of Miocene age in Britain (those formerly referred to this period having, in deference to the opinions of Continental geologists, been relegated to the Oligocene), and as the Pliocene beds are of very local occurrence, it is inferred that much of our area was, during later Tertiary times, a land surface. The effect of long-continued Pre-glacial disintegration upon this land must have resulted in the accumulation of not inconsiderable thicknesses of decayed or decomposed rock (soil), produced *in situ*, and this, before and beneath the advancing ice-sheet, would easily have been transported to localities far from the place of its origin, and thus have entered into the constitution of the Boulder Clay. After a long period of glaciation, depression set in over the British area, very much of which was submerged to considerable depths beneath the sea, as is proved by the occurrence, at present elevations exceeding 1,000 feet, in various parts of northern and middle England and of Wales, of sands and gravels containing

marine shells. Re-elevation then took place, the land emerged from beneath the sea, and for a time there appears to have been a return to conditions not altogether unlike those which prevailed before submergence. This theory derives confirmation from the fact that the marine sands and gravels are in places overlaid by the Upper Boulder Clay, another stiff, stony clay containing ice-worn stones, but differing from the Lower Boulder Clay in the presence of intercalated beds of sand, gravel, or silt, and in affording indications of a rude kind of stratification, due, perhaps, to minor oscillations of the land at about the level of the sea. This was followed by a further slow elevation, as is proved by the existence of raised beaches, while a simultaneous amelioration of the climate was accompanied by the retreat of the glaciers, which, as they receded, left their stony freight (moraines) behind them.

That, during the Glacial Period, there were many minor climatal and other physical variations is proved by the fact that even in the Boulder Clay itself there occur on different horizons beds of sand and gravel, deposits of fine clay, and layers of peat. Nevertheless, as far as geologists have been able to unravel the indications afforded by these superficial and ill-defined deposits, they appear to stand out in some such chronological sequence as the following, though one or more may be, and usually are, absent in any specified locality :—

4. Moraines, fluvio-glacial deposits, and raised beaches.
3. Upper Boulder Clay.
2. Middle Sands and Gravels.
1. Lower Boulder Clay.

It is these accumulations, often as heterogeneous in their structure as they were varied in their origin, which

rest upon the stratified rocks as represented on a geological map, and which in many localities furnish exclusively the materials both of soil and subsoil.

The period, succeeding the Pliocene, during which the glacial drifts were scattered over much of the British area, is termed the Pleistocene, Post-Pliocene, or Diluvial. The last of these terms, though the oldest, is unsatisfactory, and its use is decidedly on the wane. It was given under a misconception—an erroneous idea that the glacial drift (then called Diluvium) was the residuum left by a great deluge. When little or nothing was certainly known about the origin of the glacial deposits, it was perhaps convenient to hide our ignorance by grouping them together under the single head of Diluvium, but there is no excuse now for the retention of the term. The Pleistocene period was followed by the Recent, Alluvial, or Human period, which brings us down to the present time. The subdivision of what is termed Post-Tertiary time into Pleistocene and Recent is, however, admitted to be exceedingly artificial, and is perhaps unwarrantable. Rain-wash or brick-earth, river and marine alluvium, lake-floors and peat-mosses, sand-dunes on the coasts and trail (or loess) in the valleys, are the kinds of deposits referred to the Recent period, though some of them, particularly in the south of England, may be much older, as, for example, the accumulations of rock-rubbish, known as "head," due to the disintegrating effects of severe frost. In fact, the true glacial drift, which is scattered pell-mell over so much of the British area, hardly extends south of the Thames, and this affords the clue to the cause of the difference between the soils resting on the Chalk area north of the Thames, and those overlying the same formation south of this river. The former consist of Boulder

Clay, or of glacial sands and gravels; they are not necessarily related to the underlying rock, and are good examples of what are known as erratic or transported soils. The latter, excepting in the river-valleys, are made up of the insoluble residue which is left after rain-water containing carbonic acid in solution has dissolved out of the chalk-rock most of the carbonate of lime which enters so largely—sometimes to the extent of 98 per cent.—into its composition; it takes the form of clay-with-flints, or of somewhat light loam, and is an apt illustration of what is meant by a local, a sedentary, or an indigenous soil, that is, a soil produced *in situ*. Here, then, are two examples of totally different soils, each resting upon the same formation; and it is easy to point to the brick-earth which occupies the river-valleys in the Chalk of the South of England, and to the cold, stiff, flintless clay of the Lower Chalk, as two additional examples. By referring to other formations in the stratigraphical series, it would be possible to multiply these examples indefinitely, all tending to demonstrate that what is represented as one and the same formation on the geological map may, nevertheless, support soils of strangely dissimilar character in different localities. On the other hand, it is equally true that stratified formations of widely different lithological character may support soils of a very similar kind, owing to their being in each case covered, sometimes to a depth of more than a hundred feet, by Boulder Clay,—

> "The blue, the stiff, the never dry,"—

or other detritus of the ice-sheet.

SOIL MAPS.

It should now be apparent that, for agricultural purposes, a geological map which in the main ignores—as geological maps usually do—the character and distribution of the surface deposits, is not exactly what the agriculturist needs. But, it may be argued, a map showing surface geology alone would be incompetent to convey much, if any, information as to the subjacent "solid" geology, which is certainly too important to be lightly overlooked. This is true; and the obvious way to overcome this difficulty is, where possible, to study the two maps—the solid map and the drift map—side by side; each map is complementary of the other, and a joint examination of the two is bound to throw a flood of light on the character of the soils of the district under inspection. It will be instructive to notice the results of a few such examinations, first premising that many of the "sheets" of the Ordnance and Geoligical Surveys are obtainable in "quarter-sheets," each of the latter representing a rectangular area of about 200 square miles, the rectangle being about 17½ miles long by 11½ miles wide.

Quarter-sheet 96, S.W., occupies part of the Yorkshire area, the town of Thirsk being about 1 mile N.E. of the centre of the map, and the city of Ripon, in the S.W. corner, 10 miles distant in a straight line. Across the solid map there extend, almost in consecutive order, the outcrops of the English stratified rocks, from the yellowish Magnesian

Limestone of the Permian series on the west to the uppermost beds of the Middle Oolite on the east, the general strike being N.W. by N. to S.E. by S. The western side is occupied by an extensive, though not uninterrupted, outcrop of Magnesian Limestone. The Bunter is not seen, and there succeeds a fairly continuous band of Keuper Sandstone, about 5 miles wide, a narrow strip of this area being occupied by the alluvium and gravels of the Swale valley, and by a more extensive area of sand and gravel, of unassigned age, south of Thirsk. Passing still eastward we cross a band of Keuper Marl, its width nowhere exceeding $2\frac{1}{2}$ miles, and the town of Thirsk resting on it. Then comes on the east a very narrow but persistent band of shale and marl of Rhætic age. An outcrop of 2 to 3 miles wide of Lower Lias Shale is next seen, and there follow in rapid succession beds belonging to the Middle and Upper Lias and to the Oolitic series. The solid map further indicates the position of peaty soils, river terraces and alluvium, all regarded as of Post-Glacial age; in the index of colours, and therefore on the map, the Boulder Clay, and sands and gravels, referred to the Glacial Period, are not indicated. These latter it is the province of the drift map to show; and a most marked contrast is presented when the two maps are viewed side by side. The extensive outcrop of Magnesian Limestone in the west is almost lost to view, being reduced to a few local patches in the south, the greater part of its surface being covered up by Boulder Clay, though in its northern part glacial sands and gravels predominate. An area of some 3 or 4 square miles of peaty soil in the north-west is, of course, the same in both maps. The broad band of Keuper Sandstone is almost wholly masked either by Boulder Clay or by glacial sands and gravels. East and north of Thirsk the Lower Lias Shales

are completely hidden by Boulder Clay, which extends across this part of the area in a fairly continuous band from N.W. to S.E., attaining a breadth of 4 miles in its widest part N.E. of Thirsk. In the north-east corner of the map a triangular area of about 15 square miles is quite free from drift, and is accordingly represented the same in both maps. An example or two may serve to show the instructive character of the drift map:—For some distance around Thirsk the solid map might lead one to suppose the surface was *marl* (Keuper Marl); as a matter of fact it is chiefly *sand and gravel*, and it is this which forms the basis of the agricultural soil. Again, north and west of Ripon the solid map indicates the presence of the yellow Magnesian Limestone, whereas this district is completely covered with Boulder Clay.

Quarter-sheet 51 S.E. embraces portions of W. Suffolk and S. Cambridgeshire. In the north-east corner is Bury St. Edmunds, while on the same latitude on the west side is Newmarket. The solid map represents the whole area as Chalk, excepting a few narrow patches of alluvial deposits extending along the banks of the Lark and other rivers; hence the map is in only two colours, denoting Chalk and Alluvium respectively. The somewhat monotonous effect is entirely changed on the drift map, in which six additional colours are called into requisition, representing severally:—

Loam	Recent and Post-Glacial.
Gravel	
Gravel of Old Rivers . .	
Boulder Clay	Glacial.
Gravel and Sand . . .	
Brick-earth	

Two-thirds, perhaps even three-quarters, of the area is

now seen to be occupied by Boulder Clay, the portion not so covered being, in the main, a triangular area around Newmarket; this surface is still Chalk, though varied by considerable patches of gravels of old rivers. Many of the elongated deposits of alluvium of the solid map are flanked by Post-Glacial gravels in the drift map. The most extensive deposit of glacial gravel and sand occupies an area lying south and west of Bury St. Edmunds, while north and east of this town a line of Chalk outcrop still remains visible. Loam is of very local occurrence.

The two maps which have now been discussed are specially selected as affording good examples of the difference between the solid geology and the surface geology of the districts concerned. It will be useful now to examine the maps of an area south of the Thames, and for this purpose sheet 3 (not quarter-sheet) is taken. It comprises East Kent, Canterbury being in about the middle of the area; Margate, Ramsgate, Deal, and Dover on the east; Faversham and Ashford on the west; and Sittingbourne still farther west. From west to east, across the middle of the land area, stretches a broad band of Chalk, flanked on the south-west by the Gault and Lower Greensand Beds, and the Weald Clay. To the north, excepting in the Isle of Thanet, which is chiefly Chalk, are irregular and somewhat detached outcrops of the older Tertiaries, comprising the Thanet Beds, Woolwich and Reading Beds, Oldhaven Beds, London Clay, and Lower Bagshot Sands, with considerable tracts of alluvium south of Sheppey, and west and south of Thanet. This solid map also indicates (1) blown sand, (2) shingle, (3) brick-earth, and (4) gravel and sand. On the drift map four additional colours are employed to denote other accumulations of brick-earth, and of gravel and sand, together with "loam

on the Chalk," and "clay-with-flints on the Chalk," the two last-named deposits being derived from the weathering of the local chalk-rock. The broad area of Chalk is now seen to be extensively diversified by numerous irregular transverse bands, chiefly of clay-with-flints, but partly of loam. Deposits of brick-earth are plentifully indicated on the Tertiary strata in the northern part of the area; they are less abundant on the Gault and Greensand Beds in the south, and still less so on the Chalk itself. Though the drift map presents a very marked contrast with the corresponding solid map, the whole area is, nevertheless, entirely free from the Boulder Clay and from the Glacial Sands and Gravels which constitute so noteworthy a feature in the surface geology of much of the area north of the Thames.

The examples which have been given must suffice to show in what important respects the drift maps differ from the solid maps, and further to what extent useful agricultural information respecting the soils of any given locality may be obtained from a comparison of the two maps. But the general application of this mode of inquiry is not yet possible, owing to the backward state of the Drift Survey of England and Wales. As already stated, the survey for the 1-inch map of the solid geology was completed in 1883, whereas the survey of the surface geology was only commenced in 1872. Owing to the delicate and laborious nature of the work, a considerable time must elapse between the completion of the "drift" survey of an area and the issue of the corresponding "drift" map to the public. Still, the work is progressing satisfactorily, and from inquiries recently made at the Office of the Geological Survey of England and Wales, it appears that, down to the end of 1889, drift maps had been published, embracing the whole

of Surrey, Middlesex, Suffolk, Norfolk, nearly the whole of Kent, Cambridgeshire, Lincolnshire, Durham, Flint, and Denbigh, and portions of Sussex, Hants, Berks, Bucks, Herts, Hunts, Notts, Leicestershire, Yorkshire, Northumberland, Cumberland, Westmoreland, Lancashire, and Cheshire. This may strike the reader as a somewhat fragmentary mode of procedure, but it must be remembered that the maps are published in rectangular areas, and not in counties.

It may be objected that the 1-inch map is on too small a scale to be of much use to the agriculturist who seeks information respecting farms and estates; but this objection is more apparent than real. By taking a sheet of paper and cutting from the middle 1 square inch, areas of 1 square mile can be brought into view by laying the sheet of paper on the map. The area thus isolated or exposed, 640 acres, is about that of a fair-sized farm, and in the maps to which reference has been made, it sometimes happens that as many as half-a-dozen different colours can be included in the square inch.

A more serious defect in the 1-inch map is the absence of contour lines. It must be remembered that, not only the mineral composition, but the altitude, the aspect, and the slope are important factors in controlling or determining the character of a soil. Two soils of precisely identical lithological composition may, nevertheless, differ widely in their agricultural value; for the one may associate with a high altitude, a northern aspect, and a rapid slope, while the other at a lower level may be favoured by a southern aspect and a gentle slope; the former will receive less heat, and its "fine earth" will be more liable to be washed away in the rain-water that flows along the surface. Contour-lines appeal eloquently

to the eye, telling of abrupt slopes as they close up together, and of gentle declivities as they recede from each other. They are capable of showing, at a glance, the altitude, the aspect, and the slope. In connection with this point, however, it may be well to add, that the 6-inch Ordnance map shows the contours, so that in cases in which the geological solid map, the drift map, and the 6-inch Ordnance map of a district can all be inspected together, it is of course possible to acquire very much valuable information about the soils of a farm, or of an estate, without actually visiting it. Nor must it be forgotten that to the geologist the outcrops themselves of the different strata, as indicated on a map, go a long way to compensate for the absence of contours.

But, even with the three maps just mentioned, there would still be a link missing. The geological map shows what are the underlying strata, the drift map indicates the mineral matter which is actually at the surface, and from the decay of which the soil is formed. But the drift map affords no information as to the thickness or depth of the superficial deposit, nor as to whether there is, or is not, any other deposit lying between the superficial one and the stratified rocks below. This is obviously a very important matter in connection with water-supply and drainage. Thus, suppose the drift map to indicate a surface accumulation of glacial sands and gravels resting upon what the solid map represents as an outcrop of the Chalk, it might be hastily inferred that from the surface downward there were only permeable strata. But it would be quite possible for the sands and gravels to rest upon the Lower Boulder Clay, only the latter being in contact with the subjacent Chalk; in this case the impermeable clay would resist the downward passage of the

water derived from the rainfall on the sands and gravels, and land springs and surface wells would be the result. On the other hand, in the case of Boulder Clay resting upon sands and gravels, and these in turn upon the solid (let us suppose impermeable) rocks below, the drainage of the clay soil might be disposed of by sinking absorption wells into the intervening permeable sands and gravels. The drift maps, by denoting the limits or boundaries of the surface accumulations, indicate clearly enough where these deposits thin out at the surface and give place to others on the same horizon, and, to some extent, it is discoverable from them whether more than one kind of drift deposit exists between the soil and the underlying solid rock. It would be very useful to know, in the case of surface accumulations, what might be termed the contours of the underlying or deep face of such deposits, as then their varying depth could at once be ascertained. The late Mr. Trimmer, who devoted considerable attention to the study of soils, and since whose time the subject has been almost at a standstill, published in 1850 a 10-page pamphlet, now difficult to obtain, bearing on the title-page: "Proposals for a Geological Survey specially directed to Agricultural Objects. By Joshua Trimmer, F.G.S., at present attached to the Geological Survey of Great Britain." His chief object was the preparation of geological maps on which would be shown "those superficial deposits which are omitted from ordinary geological maps, but which are, obviously, of the most importance to the agriculturist." He constructed a table in which the italicized letters of the alphabet are made to denote the various kinds of soils, whether siliceous, loamy, clayey, peaty, marly, or calcareous, with the varieties of each. Then such a symbol as this on the map,—

$$\frac{\frac{f^1\ 18}{gr.\ 10}}{s.\ 20}$$

would mean that, at the point where the sign occurs, "the soil consists of erratic sandy loam 18 inches deep, on a subsoil of gravel 10 feet deep, and a substratum of sand 20 feet deep." These conditions may vary within very short distances, and even in the same field, to

$$\frac{\frac{f^1\ 6}{gr.\ 3}}{s.\ 20}$$

or "erratic sandy loam 6 inches, on gravel 3 feet, and sand 20 feet deep." They may even vary to the following, where the surface soil is all that belongs to the erratic class,

$$\frac{f^1\ 6}{ch.\ 30\ +}$$

"erratic sandy loam 6 inches, on chalk, of depth undetermined, but more than 30 feet." The following example shows the manner in which a local or indigenous soil would be noted :—

$$\frac{f^1\ 6}{sn.\ 30\ +}$$

that is, "local sandy loam 6 inches, on sandstone, of depth undetermined, but more than 30 feet." It will be noticed that the figures of the top line always denote

inches, and of the other lines feet. By acting upon these suggestions of Trimmer, it appears likely that agriculturists might usefully supplement the published drift map of any area under their charge by annotations of this kind; well-sinking, deep drainage, and the like would afford the necessary data. Trimmer's method is adopted in the field work of the Geological Survey, and will be found recorded on the manuscript maps of the Survey.

Trimmer enunciated comprehensive and definite views respecting Agricultural Geology, which he considered should embrace the classification of soils, both as regards their lithological character and their mode of origin; their horizontal and vertical distribution; the occurrence of mineral fertilizers, and of materials suitable for building, draining, and road-making; springs and water-supply; the depths and distances of drains; and the relation of soils to the distribution of population. He estimated that an examination of the soils of England and Wales for the purpose of determining their variations, and their relations to the rock formations of our geological maps, would require the constant work of ten Surveyors for thirty years; and, as has just been noticed, his experience led him to the conclusion that not the mere surface alone, but the thickness and lithological character of all the beds between the solid rock and the soil should be indicated.

No more fitting tribute to the soundness of Trimmer's views could be desired than the following remarks made by an experienced agriculturist, Mr. Albert Pell, in the *Journal of the Royal Agricultural Society of England*, Part I., 1890:—

"We have abundance of splendid geological maps of Great Britain, but of surface maps next to none, if we

except the 'drift' maps of the Ordnance Survey of the eastern portion of England; and it is, after all, with the surface that the farmer has to do. A geological El Dorado of fertility may be below him at a depth of four feet; but if the space between that and the sole of his plough or the hoof of his live-stock be taken up by a layer of boulder clay, it might as well be on the other side of the world, for all the good it will do him."

England, to a greater extent perhaps than any other area of equal size upon the globe, is particularly rich in the number and variety of the geological outcrops within its borders. In the study of these, and of their relations to each other and to the superincumbent accumulations of drift, will be found the key to the characteristic features of Agricultural England, as well as the explanation of the striking transitions—so well described by the late John Algernon Clarke in the *Journal of the Royal Agricultural Society*, 1878—

"From the warm hop and fruit grounds of Kent and the dry Chalk downs of Sussex to the bleak northern Cheviots and the stormy fells of Cumberland; from the rich wheat and root lands of East Yorkshire to the moors of the West Riding and the mosses of Lancashire; from the fat marsh lands and high-cultured wold and heath farms of Lincolnshire to the mountain ranges of Carnarvon; from the arid barley lands of East Anglia and the corn-growing clays of Essex to the moist uplands and lofty sheep-walks of South Wales; from the hay meadows of Middlesex and the sands of Surrey to the sheep-clad hills of Dorset, the rank pastures of Somerset, and the corn and dairy farms, mild garden grounds, apple orchards, and granite wilds of Devon and Cornwall."

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